State of Rhode Island and Providence Plantations

ANNUAL REPORT

OF THE

BOARD OF PURIFICATION OF WATERS

MADE TO

HIS EXCELLENCY THE GOVERNOR

FOR THE

FISCAL YEAR ENDING DECEMBER 31, 1922

THE LIBRARY OF THE
OCT 16 1940
UNIVERSITY OF ILLINOIS

PROVIDENCE
E. L. FREEMAN COMPANY, PRINTERS
1923

State of Rhode Island and Providence Plantations

ANNUAL REPORT

OF THE

BOARD OF PURIFICATION OF WATERS

MADE TO

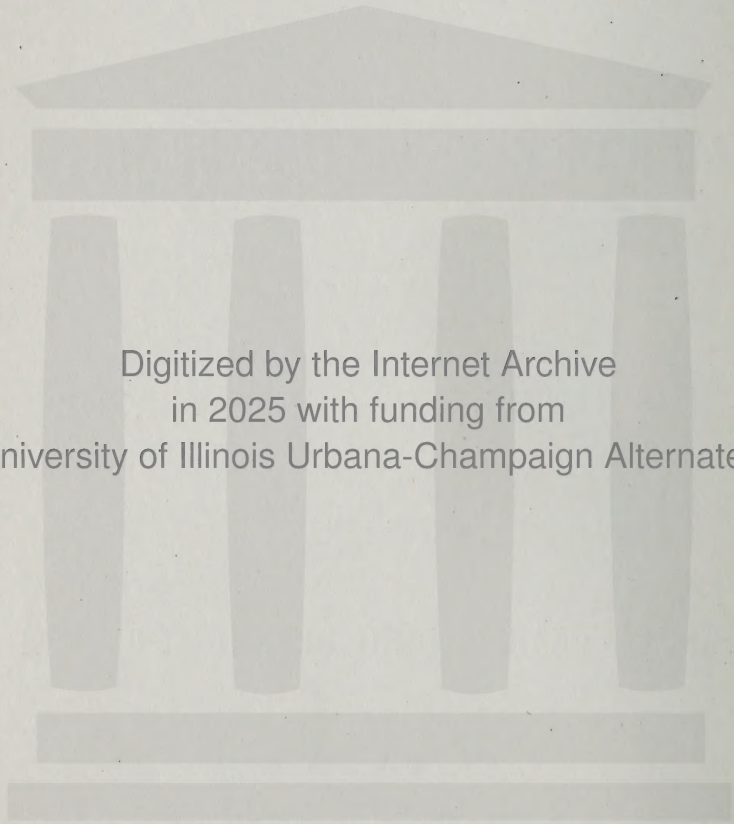
HIS EXCELLENCY THE GOVERNOR

FOR THE

FISCAL YEAR ENDING DECEMBER 31, 1922

THE LIBRARY OF THE
OCT 16 1940
UNIVERSITY OF ILLINOIS

PROVIDENCE
E. L. FREEMAN COMPANY, PRINTERS
1923


Digitized by the Internet Archive
in 2025 with funding from
University of Illinois Urbana-Champaign Alternates

https://archive.org/details/reportofboardofp1922rhod

R346
1922

THIRD ANNUAL REPORT

To His Excellency the Governor of the State of Rhode Island and Providence Plantations:

SIR:—The Board of Purification of Waters has the honor to make to you this its annual report concerning the subject of the purification of the waters of the state and the activities of the Board from the first day of January, A. D. 1922, to the first day of January, A. D. 1923, as follows:

Organization and Membership.

Giles W. Easterbrooks, of Pawtucket, whose term of office as a member of the Board expired on the thirty-first day of January, 1922, was reappointed by the Governor with the advice and consent of the Senate to hold office until the first day of February, 1925.

The members of the Board during the year 1922 were as follows:

THOMAS H. CONNOLLY, *Chairman*, of Warren.
GILES W. EASTERBROOKS, of Pawtucket, and
HAROLD T. MERRIMAN, of Providence.

The staff of the Board includes: W. Louis Frost, Clerk of the Board, of Providence; Stephen DeM. Gage, Sanitary Engineer, of Cranston; Philip C. McGouldrick, Chemist, of Providence; John T. Smith, Special Investigator, of Warren; and Doris W. Minckler, Stenographer, of Providence.

During the summer months of 1922 the Board also had in its employ a field force consisting of Nelson M. Fuller, Kenneth V. Hill, Frank B. Littlefield, and J. Albert Gage, who were engaged under the direction of the Sanitary Engineer of the Board in a survey and study of Narragansett Bay and the various rivers of the state, for the purpose of ascertaining the actual condition of the public waters as to pollution and their ability to purify themselves.

The offices of the Board at Rooms 307-A and 308 in the State House, Providence, have continued to be open daily except on Sundays and legal holidays.

The Law and Procedure.

The Board of Purification of waters was created by Chapter 1914 of the Public Laws, passed at the January Session, 1920, which became effective on the first day of September, 1920. This chapter is entitled "An Act to Prohibit and Regulate the Pollution of the Waters of the State" and was amended in certain particulars by Chapter 2090 of the Public Laws, passed at the January Session, 1921.

By Section 3 the Board is authorized and directed to regulate or prohibit the pollution of the waters of the state in accordance with the provisions of the act.

There are two courses of action provided by the law which may be taken:

FIRST. Conference. The Board, either of its own motion or at the request of any person discharging or emptying sewage, or causing or permitting sewage to be discharged or emptied into any of the waters of the state, shall consult with and advise such person as to the best practicable and reasonably available system or means to prevent such sewage from polluting the waters of the state.

SECOND. Prosecution. After an investigation, which shall include a hearing granted to any person believed to be polluting, if the Board shall find that such person is polluting the waters of the state, it may enter an order directing such person to adopt or use or to operate properly, as the case may be, some practicable and reasonably available system or means to prevent such pollution, having due regard for the rights and interests of all persons concerned.

Polluting in violation of any such order of the Board is punishable by a fine of not more than five hundred dollars or by imprisonment for not more than one year or by both such fine and imprisonment; and every such person shall be deemed guilty of a separate and distinct offense for each month or part thereof during which such pollution in violation of an order of the Board shall be repeated or continued.

Under authority of the act rules have been adopted for procedure before the Board.

Meetings and Routine.

In order that the Board of Purification of Waters may without undue delay properly advise persons discharging sewage into the public waters as to the best practicable and reasonably available

system or means to prevent such sewage from polluting, the Board has secured the services of sanitary experts and gathered various preliminary information. A survey of those public waters of Rhode Island most utilized for sewage disposal has been made to find out how far they are now polluted and how far they are capable of safely receiving sewage effluents. The Board has personally visited various sewage treatment plants in operation and some under construction, in Massachusetts, Connecticut and Rhode Island, observed the manner of operation of these plants, and familiarized themselves with some of the modern methods of sewerage treatment and disposal.

During 1922 the Board met regularly and also held numerous special meetings and conferences. Eleven personal visits of inspection of municipal methods of sewage disposal and of private places of business have been made by the members during the year, for the purpose of observing the disposal processes being employed in these places and ascertaining the possibilities for reducing pollution of the public waters. Among the places visited were the plants of the following concerns: American Electrical Works, Washburn Wire Company, Sayles Finishing Company, Phillipsdale Paper Company, and O'Bannon Corporation, all in East Providence, Colored Worsted Company, in Providence, and Star Carbonizing Company, in Woonsocket.

At the invitation of the Connecticut Chamber of Commerce, Thomas H. Connolly, Chairman of the Board, and Stephen DeM. Gage, its Sanitary Engineer, attended the annual meeting of the Chamber of Commerce at Hartford on the twenty-fifth day of May, 1922, and delivered addresses on the methods used in handling the pollution problem in Rhode Island.

On the thirteenth day of July, 1922, a trip was made by the Board up the Seekonk River by boat for the purpose of observation.

At the invitation of the State Board of Health of the State of Connecticut, the Board of Purification of Waters was represented by W. Louis Frost, Clerk of the Board, at a Public Hearing given in Pawcatuck, Connecticut, on the fifth day of October, 1922, for the purpose of obtaining the sentiments of the residents of Pawcatuck and Westerly concerning the elimination of pollution from the Pawcatuck River.

The Board went to the City of Worcester, Massachusetts, on the second day of November, 1922, where an inspection was made of the present municipal sewage disposal plant and the new modern plant

consisting of Imhoff tanks and sprinkling filters now being constructed by that city. On the same day the Board proceeded to the City of Fitchburg, Massachusetts, where an inspection was made of the Imhoff tanks, sprinkling filters and other sewage disposal apparatus in use at that city.

The Board has also made several personal inspections of the municipal sand filter beds at Woonsocket and of the methods of operation by the city officials in charge.

During the year the Special Investigator of the Board has made three hundred twelve visits of inspection and reported thereon. These inspections, which covered both public and private sources from which pollution might enter the public waters, included the usual constant surveillance of the plants of the various oil companies and of the steamers bringing cargoes of oil into the ports of the state. In connection with the surveillance of the sources of oil pollution the Board has continued its operation of a power boat throughout the year and has received daily written reports of the observations made by the person in charge of this boat.

Numerous special reports have been made to the Board by its Sanitary Engineer, its Chemist, and the members of its summer field force. These reports include among other things findings upon matters investigated as the result of complaints and comments upon conditions observed during the summer survey of the streams.

All reports are numbered, adequately indexed, and filed for future reference.

All the municipal sewage treatment plants have been under constant supervision throughout the year and regular analyses of the sewage before and after treatment have been made in the laboratory of the State Board of Health under a co-operative arrangement with this Board.

Through the courtesy of the State Board of Health the services of Stephen DeM. Gage, Sanitary Engineer, have continued to be available to the Board of Purification of Waters and the laboratory under the jurisdiction of the State Board of Health used for chemical analyses required by this Board, although owing to lack of laboratory space the amount of laboratory work done has been limited.

Proceedings.

All complaints made to the Board concerning the pollution of the waters of the state have been immediately investigated. Com-

plaints of this nature have been few in number and informal in character.

On July 24, 1922, complaint was made that dredged material deposited at the Prudence Island dumping ground was creating a nuisance. A preliminary investigation was made by the Board. Several conferences were had with the United States Engineer Office concerning the use of the dumping ground which is fixed by the War Department. As a result the Board has secured assurances from that department that all reasonable precautions will be taken to limit the dumping at the Prudence Island dumping ground so that no offense will hereafter be given the summer residents on the shores of that island and that dumping of material other than sand will be restricted, during the summer months at least, to the southern portion of the ground.

Although the law specifically provides that the Board may conduct hearings upon formal complaints, no person has yet initiated any such proceeding before the Board. The Board believes this to be an indication of public approval of its policy of approaching the subject of eliminating pollution by seeking the co-operation of oil companies, manufacturers, municipalities, and others.

It appears that this manner of handling the pollution problem as it affects large and growing populations has the approval of the highest court in the country. In the case of *The State of New York* vs. *The State of New Jersey and Passaic Valley Sewerage Commissioners*, decided by the Supreme Court of the United States on May 2, 1921, Mr. Justice Clarke said:

"We cannot withhold the suggestion, inspired by the consideration of this case, that the grave problem of sewage disposal presented by the large and growing population living on the shores of New York Bay is one more likely to be wisely solved by co-operative study and by conference and mutual concessions on the part of representatives of the states so vitally interested in it than by proceedings in any court however constituted."

Conferences looking to the proper operation of sewage disposal plants and the elimination of pollution have been held by the Board of Purification of Waters during the past year with representatives of the City of Central Falls, the Town of East Providence, the City of Woonsocket, and the City of Pawtucket. A consultation was also had between the Board and the superintendent of the East Providence Plant of the Gulf Refining Company.

Oil Pollution.

It has been reported to the Board from many sources that the methods adopted by it for the prevention of oil pollution have resulted in great improvement in this respect. The waters have been generally free from this most annoying and dangerous form of contamination during 1922.

Owing to the number of oil companies located on or near the banks of Narragansett Bay and its tributaries, and to the increased use of fuel oil by manufacturers and others in Rhode Island, the potential sources of oil pollution are many. There is the constant danger of breakage of oil pipes and containers with the resultant escape of their contents. As oil is fluid it may enter the rivers after flowing long distances, as for example through municipal sewers. Other possible causes of oil spills have been set forth in previous reports. The Board is trying by every possible means to reduce such mishaps to a minimum. Nevertheless even with the exercise of all due precautions by users and handlers of oil, there may be an occasional annoying scum of oil due to some accident. There is also always present after a storm a trace of light oil which is washed from the streets.

A record is made by the employees of the Board of such days as oil is observed by them on the public waters. During 1922 there have been comparatively few serious cases of oil pollution.

However, during December, for several days there were large quantities of oil in the Providence and Seekonk Rivers. This was the result of two separate accidents far removed from each other. Both were the development of leaks in manufacturing plants using fuel oil. One was at a plant near the bank of the Woonasquatucket River in Providence, and the other was at a manufactory in the City of Pawtucket at some distance from the river. Although a very large number of barrels of fuel oil, said to be seventy barrels during a period of twenty-four hours, escaped from the Pawtucket manufactory, the management of this concern had no knowledge of the escape of this oil until it was brought to their attention through investigators for the Board of Purification of Waters who had traced the discharge to a municipal sewer outlet and with the aid of city officials had located the point of entrance into the city sewer. In the case of the above described discharge of oil into the Woonasquatucket River, booms were installed under the direction of the Board of Purification of Waters on the surface of the river below the point of entrance of the

oil to prevent its continuing to pass down the stream and directions were given to skim off the oil that gathered behind the booms. Request was made for like procedure by the Pawtucket city authorities, but the city officials concluded that this precaution was unnecessary at that time.

As a result of its experience in this matter the Board plans to gather complete data showing all persons and concerns using fuel oil and to require methodical inspections by such persons and concerns of their own oil storage facilities.

Methods already used by the Board to prevent oil pollution include:

1. The adoption by order of the Board entered on the 19th day of November, 1920, of rules and regulations to prevent the discharge or escape of any petroleum, gasoline, kerosene, tar, oil, or any product or mixture thereof into the public waters of the State. These rules prohibit deliberate discharge of oil, placing of oil in dangerous places, pumping bilge water from oil carrying vessels, and washing of oily receptacles near the public waters, and require the posting of copies of the rules in conspicuous places.

2. The securing of a United States naval order from the Chief of Naval Operations at Washington, D. C., forbidding discharge of oil by naval vessels.

3. The construction and installation of safeguards at all oil companies which include among other things, bulkheads and booms, wooden plugs in scupper holes of vessels, and oil separators at all waste outlets, and the exercise at such plants of watchfulness and cleanliness.

4. The operation of a power boat constantly on the watch for signs of oil in the bay.

5. Constant surveillance by investigators for the Board and regular reports upon conditions.

Oil Pollution of Ocean Beaches. The Board has made various inquiries relative to the extent of oil pollution of the ocean beaches of Rhode Island. It appears that occasionally there are patches of oil washed from the ocean onto the beaches. These patches of oil do not make their appearance until it is practically impossible for the Board with their present facilities to ascertain the source of this pollution.

However, at about nine o'clock of the night of October 10, 1922, the tank steamer Swiftstar II of the Mallory Line bound for Fall River, Massachusetts, with a cargo of about 70,000 barrels of oil went aground about two miles off the South Light at Block Island and jettisoned the greater part of her cargo of oil in order that the wrecking crew could pull her from the rocks. The Providence Journal under date of October 16, 1922, stated that "the dumping of the major part of the cargo of oil into the sea is said to have wrought havoc with the fish of the sea, and the west shore of Block Island is said by fishermen to be covered for a distance of a mile and a half with dead fish of all the smaller varieties. The surface of the water for some distance from shore is also covered with a thick oily scum."

About a week later oil was noticed along the beach at Matunuck and vicinity which remained for a considerable time. The oil was very light and did not make a deposit on the sand. The rocks on the beaches, at low water were covered with a thin film of oil which seemed to flush out at high tide. According to fishermen this oily film could also be seen on the surface of the water for about half a mile out to sea. The oil also came into Point Judith Pond in considerable quantities at flood tide and was deposited on the marshes. It is believed that this oil came from the Swiftstar II as the wind at the time of the wreck was strongly southwest most of the time. The oil came ashore over a stretch which probably did not extend further west than Green Hill or further east than Point Judith.

It is expected that there will soon be an effective control by the Federal Government of oil pollution at sea. While the several states probably have the right to prevent the discharge of oil within the three mile limit along their respective ocean shores, the National government has at present various facilities not possessed by the states for keeping an oversight of oil carrying vessels and for the prompt discovery and report of any oil pollution as well as a longer arm with which to enforce any necessary oil regulations than have the states. Several bills are pending in the United States Congress which are intended to correct the present evils arising from discharge of oil by ships at sea. It is hoped that a Federal act on this subject will shortly be enacted.

Manufacturing Wastes.

There is a commendable disposition on the part of manufacturers whose factories are located on the banks of the streams to aid in

eliminating pollution from their plants. A number of such concerns have already installed treatment plants and others are contemplating the construction of purification systems.

Many private concerns, however, are in the position of being obliged to wait until municipal sewerage facilities are furnished for the receipt of their manufacturing wastes.

Surveys and reports have been made to the Board by its engineers concerning the treatment of the manufacturing wastes of several concerns and the facts thus established are being considered by the sanitary advisors of these plants with the object of devising such further improvements as may be necessary to prevent reasonable ground for complaint that they are causing excessive pollution.

Several manufacturers have submitted to the Board for approval statements and plans for systems or means for the prevention of pollution which they have adopted or desire to adopt. All orders of approval made by the Board have been after consideration and report by its Sanitary Engineer and have been provisional in such particulars as seemed necessary to protect the interests of the public.

Municipal Sewage Disposal.

A detailed description of the systems of sewerage and sewage treatment employed by the different cities and towns is contained in the report of the Board for 1921.

Following is a summary of the conferences which have been held between representatives of the various municipalities and the Board of Purification of Waters since the organization of the Board, with notes on the progress made by the several municipal divisions. The object of these conferences has been to enlist the co-operation of the cities and towns in the elimination of any reasonable ground for complaint concerning the disposal of their sewage. Stenographic reports of these discussions are on file in the office of the Board.

PROVIDENCE.

October 7, 1920. At a conference with representatives of the City of Providence concerning the discharge of raw sewage through the Dorrance Street sewer outlet, it appeared that the main sewer in Allens Avenue was out of commission for repairs. The City promised when the main sewer had been repaired to dredge out the Dorrance Street slip.

March 17, 1921. The operation of the treatment plant at Fields Point was discussed. It was agreed by the city representatives that Providence would resume chemical precipitation of its sewage and removal of the pressed sludge by scow which had been discontinued during the war.

July 7, 1921. The escape of oil into the Providence sewers being under consideration, the city officials agreed to secure an amendment to the city ordinance so as to prohibit oil being deposited in the sewers.

August 16, 1921. It was stated by the city officials that Providence would arrange to eliminate the discharge of its raw sewage into the Seekonk River and pipe this sewage to the municipal plant at Fields Point. Report was made that the precipitation of the municipal sewage by lime treatment, pressing of the sludge and its removal by scow had been resumed and that the sterilization of the effluent with chlorine which had been carried on during the war was being continued; also that the city ordinance had been amended so that it now prohibits depositing of oil of any kind in the sewers, and that the city was making a survey of all oil burning plants and some 2,500 garages with the object of stopping oil pollution from these places.

December 8, 1921. The city stated that it would apply at the next session of the General Assembly for authority to acquire the necessary easements for the lateral sewer along the Seekonk River and for financing the project, and likewise for the construction of the Manton Avenue sewer so-called to aid in the elimination of pollution from the Woonasquatucket River. These projects will each cost about $300,000.

Progress: The General Assembly by Chapter 2246 of the Public Laws, passed at the January session, A. D. 1922, authorized the City of Providence to acquire a right and easement for a sewer in extension of the present Manton Avenue sewer. The completion of this sewer is expected to prevent some pollution of the Woonasquatucket River. Chapter 2247 of the Public Laws, passed at the same session, gives the City like power for the construction of a sewer along the westerly side of the Seekonk River. When completed the municipal sewage now discharging into the Seekonk River will be carried to the municipal plant at Fields Point for treatment. At the time this report was written the city has made the necessary condemnation and appropriations for that purpose.

EAST PROVIDENCE.

June 23, 1921. At a conference concerning the disposal of sewage from East Providence the Board was informed that the Town was ready to begin the installation of a treatment plant whenever other towns were compelled to do likewise.

December 22, 1921. Representatives of the Town of East Providence reported that a committee had been appointed by the Financial Town Meeting held in November, 1921, to investigate the matter of disposal of sewage and to report its findings and recommendations at the annual financial town meeting in November, 1922. The Board was also informed that the representatives of the Town present at the conference would communicate to the special committee the desire of the Board to know what plans they have formulated and to communicate these to the Board before March 15, 1922.

March 8, 1922. The town officers were requested to confer with the Board and report the progress being made, and the Board was informed on March 11, 1922, by the president of the town council that it was deemed inadvisable to send representatives to the Board's meeting.

July 27, 1922. Request was made by the Board for information as to the progress being made by the special committee on sewage disposal. Town representatives informed the Board that the special committee took the position that they should make their report only to the financial town meeting.

October 26, 1922. The Board addressed a communication to the Financial Town Meeting stating:

"(1) That it is absolutely necessary that, through the proper and prompt working of the machinery of the Town government, adequate provision be made for the installation and operation, in the immediate future, of some practical and reasonably available system or means to prevent the pollution of the waters of the State by the sewage of the Town of East Providence.

"(2) That unless the Board of Purification of Waters has some reasonably definite information that such steps are being taken it will be under the necessity of entering an order directing the Town to install such a system."

December 7, 1922. At a conference with representatives of the Town and the special committee on sewage disposal the Board was informed that the special committee in its report to the financial town meeting had made the following recommendations:

"Your Committee, is of the opinion that the Town should cooperate with the Board of Purification of Waters in aiding it to clear the Seekonk River and to that end recommends:

"*First:* That all sanitary sewage and trade wastes be diverted from the Taunton Avenue and Warren Avenue combination sewers to the sanitary system, thereby eliminating a source of nuisance under the Washington Bridge at the outlet of the combination system.

"*Second:* That a Committee of Taxpayers be appointed who shall make with the aid of an expert engineer an exhaustive study of the conditions involved.

"*Third:* That the Town appropriate for the use of said Committee the sum of $3,000, which sum, or so much thereof as is necessary be used by said Committee, in employing an expert sanitary engineer, in the preparation of plans for a system of sewage disposal and in the compilation and presentation in proper form to the Town of estimates of the cost of construction of such a system."

It was also reported at this conference that the financial town meeting had adopted the following resolution:

"RESOLVED, that a Committee of Taxpayers, five in number, who shall serve without compensation, be appointed to continue the investigation of the matter of disposal of sewage, to present plans for and estimates of cost of a disposal system and structures appurtenant thereto, together with a location or locations therefor and to report its findings and recommendations to the Annual Financial town meeting in November, 1923:

"That for the accomplishment of the foregoing purposes the sum of $3,000 or so much thereof as is necessary, be and it hereby is appropriated:

"That William C. Viall, Frederick W. Hauck, James H. Lenardson, G. Frederick Frost and William J. Kennedy be chosen as said committee, and that the Town Council shall fill any vacancy or vacancies which may occur in said committee."

In a letter sent to the special committee above named and to the town council of East Providence dated December 7, 1922, the Board of Purification of Waters stated:

"That it expects the Town of East Providence to show its good faith in the matter of the installation of a disposal plant for the sewage of said town by taking the following steps:

"1. The Town to apply at the January session, A. D. 1923, of the General Assembly for legislative permission to issue bonds to take care of the cost of construction and other capital expenses of a sewage disposal plant for East Providence.

"2. The Special Committee of the Town to submit definite construction plans to the Board for its approval on or before the first day of June, 1923.

"3. The Town to start construction of the proposed sewage disposal plant as soon after the approval of said plans as the contracts for such construction can be let."

Progress: At the time of writing this report the Board is in receipt of a letter from the East Providence special committee stating that "on January 27th the Committee entered into a contract with the City-Wastes Disposal Company of New York for a thorough investigation of the matter of Sewage Disposal throughout the Town and for detailed plans for treatment works to care for the present needs of the Town." The Board has not been informed when this investigation is to be completed.

CENTRAL FALLS.

June 30, 1921. The City of Central Falls was invited to send representatives to confer with the Board at a meeting held on this day concerning the disposal of sewage from that city. A representative of the City appeared but he stated that he could give the Board no information as to the plans of the City.

July 21, 1921. At a conference with the Board representatives of Central Falls stated that the City was anxious to co-operate with the Board in the matter of securing adequate treatment of its sewage. There was a general discussion of methods available for improving the quality of the effluent from the treatment plant and concerning the future treatment of the municipal sewage now flowing into the Blackstone River in a raw state.

January 12, 1922. Officials of Central Falls informed the Board that the Board of Aldermen of that city had appointed a committee to co-operate with the Board of Purification of Waters and to assist in every way possible in relieving harmful conditions. It was stated that the trench through which the effluent from the treatment plant flows into the Moshassuck River would be cleaned, and that a method of properly caring for the sewage on the Blackstone River side of the city was under consideration. There was a further discussion concerning methods of preventing pollution of the Moshassuck River due to the entrance therein of the effluent from the municipal sewage treatment plant. A copy of a "Report of Sewage Disposal at Central Falls," prepared by the Sanitary Engineer of the Board for its use,

containing, besides a description of conditions, suggestions how better purification could be obtained, was handed to the committee.

Progress: The trench into which is discharged the effluent from the Central Falls treatment plant was cleaned and straightened by the City during the summer of 1922. This trench follows the course of the brook for nearly a mile through a swamp and connects with the Moshassuck River. It is hoped that the work on the trench will reduce the former nuisance.

PAWTUCKET.

June 10, 1921. Officials representing the City of Pawtucket informed the Board that a firm of expert sanitary engineers was then engaged in a study of the sewage disposal requirements of the City of Pawtucket and that it was planned after necessary preliminary investigations to construct an adequate purification plant for the treatment of the sewage of Pawtucket with the object of eliminating the discharge of any of the municipal sewage in a raw state into the Blackstone River.

Progress: The engineers employed by Pawtucket are expected very soon to complete their report upon the best method of treating the sewage of this municipality. The City was empowered by Chapter 2290 of the Public Laws, passed at the January session, 1922, to acquire lands and easement for sewage works.

WOONSOCKET.

June 30, 1921. Woonsocket officials conferred on this day with the Board concerning their municipal system of sewage disposal.

July 21, 1921. After a personal visit by the Board to the purification works of the City of Woonsocket there was a further discussion with city representatives concerning the adequacy of the municipal treatment plant and of the methods then being used in operating the same. "A Report on Woonsocket Sewage Disposal Plant" by the Sanitary Engineer of the Board containing suggested remedies for the difficulties encountered by the City in operating its sand filter beds was read and a copy delivered to the city representatives.

May 25, 1922. A city official reported at a conference with the Board that authority had been obtained to issue bonds to cover the cost of five more sand filter beds and some sort of settling basin, but that no appropriation had been made for the additions.

December 28, 1922. There was a further discussion on this day with Woonsocket officials as to the necessity for by-passing of sewage at the municipal treatment plant. It was reported that the necessary money had been appropriated for additional sand filter beds and a storage basin for the sewage.

Progress: The operation of this municipal plant has been closely observed by agents of the Board of Purification of Waters and suggestions have been made from time to time of reasonably available means of securing the most efficient results from the municipal sand filters and to prevent undue by-passing of sewage.

Plans are very nearly completed by the City for seven additional sand filter beds and a storage basin for the sewage. An appropriation has been made for this work to be spent under the direction of the sewer commissioners, the actual construction to be under the supervision of the city engineer. At the time of the writing of this report the Board has been informed that work has started on the excavation for the new filter beds and it is the intention of the contractors to push the work as fast as possible.

BRISTOL.

July 28, 1921. Officials of the Town of Bristol on this day conferred with the Board relative to the need of a purification plant in that town. The Town took the position that it is not polluting within the meaning of the law and that the position of its sewer outlets is such that the discharge is harmless.

Progress: The Board is considering the matter in connection with occasional chemical examinations of the waters of Bristol Harbor. Preliminary observations were made during the summer of 1922.

EAST GREENWICH.

August 4, 1921. The Board had a conference with officers of the Town of East Greenwich relative to the need for purification of the sewage from that town. The town representatives stated that all the municipal sewage is discharged through a single outlet at the foot of King Street about 200 feet out in the bay, and that the treatment of this sewage had never been seriously thought of in any way. It was understood that the matter would be discussed by the town officials and that they would communicate with the Board at a later day.

WARWICK.

August 4, 1921. The Board discussed with the president of the town council of Warwick the possibility of the adoption by that Town of a municipal system of sewerage and sewage disposal. Conditions at Oakland Beach and at Apponaug were described.

Progress: As sewerage systems are dependent upon a supply of running water, the installation of a water system at Oakland Beach is necessary before the population can be properly sewered. In a letter dated August 4, 1921, the Board requested the town council to take some action to correct offensive conditions of the cove and river at Apponaug. A communication was received from the town clerk September 15, 1921, stating that the matter had been taken into consideration and reporting progress upon the same.

WESTERLY.

Progress: No official conferences have been held with this municipality, but inspections of the progress being made in carrying out the municipal plan for sewerage and treatment of the sewage have been made. The treatment plant is nearing completion. The pump house is already finished. The automatic pumps are installed and now operating. A grit chamber and a screening arrangement is contained in the pump house. Only such domestic sewage as previously entered the Pawcatuck River is at present being discharged through the plant. It is expected that the system will be completed during 1923 by the construction of an Imhoff tank, sludge beds, and intermittent sand filters. The plans provide for the care of a possible increase in the volume of sewage in the future.

While the progress already made by the municipalities is encouraging, nevertheless the Board believes that more energy should be shown by all the municipalities in completing the steps necessary to secure adequate treatment of their sewage. Those municipalities without treatment plants are endangering the health and comfort of the people. Cities increasing in size and with treatment plants overburdened and constructed on principles now out of date should at least begin the study of the modern improvements in sewage disposal methods and plants with particular reference to the construction and adoption of such additions and methods as may be available and necessary to prevent such municipalities from overloading the public waters with inadequately treated sewage effluents.

Condition of Rhode Island Rivers.

Throughout the state there are minor sources of pollution of the public waters, as for example, sink drains of summer cottages and other buildings on the shore of Narragansett Bay and waste outlets of small capacity on the banks of rivers. These sources of pollution should be eliminated as well as larger sources of pollution. The Board of Purification of Waters seeks the co-operation of all persons in preventing nuisances from all such sources.

But, as this Board stated in its report for 1921, the elimination of pollution by the larger offenders must be secured before satisfactory conditions will exist. By the larger offenders the Board means those manufacturing concerns and municipalities which are now discharging large volumes of raw or incompletely purified sewage and waste liquors into our public waters.

Already much has been done towards the treatment of these wastes so that the same shall be of a character which will not burden the public waters. But much more remains to be done. The reports of the sanitary experts of the Board on the conditions of the Seekonk, Moshassuck, Woonasquatucket and Providence Rivers, which are appended hereto and made a part of this report, show an alarming condition of these streams.

It is well recognized that the waters of a river in its natural state are saturated with oxygen. As the water becomes polluted this oxygen is absorbed by the sewage in the attempt of nature through the action of bacteria and other biologic organisms to render that sewage innocuous. This process of self purification in a polluted stream is known as oxidation, and continues, without nuisance so long as the supply of oxygen in the water is sufficient. If the amount of oxygen in the water is insufficient, however, decomposition of the polluting matters still continues by another process known as putrefaction, in which offensive odors and black discoloration of the waters are produced.

It is perfectly evident that if enough sewage in a raw state is deposited in a river the oxygen will be entirely consumed in the attempt of nature to destroy the sewage, and that a nuisance must result. The river becomes dirty looking and malodorous and is offensive both to sight and smell. The remedy for such a condition is of course to reduce the amount of pollution to a point where the supply of oxygen in the water is ample to permit the purification to be

completely carried out by the oxidation process, and this may be accomplished by limiting the amount of entering sewage or by purifying the sewage before it is discharged into the stream.

It is evident also that determinations of the amount of oxygen present in a polluted river furnish us with a measure of the probability that that river will or will not become a nuisance. Experience has shown that if the water contains less than fifty per cent. of its normal oxygen content, offensive conditions due to lack of sufficient oxygen are very likely to occur in warm weather when biological life is most active. It is generally accepted therefore that a river is in an unsafe condition if it contains less than fifty per cent. oxygen saturation. A more detailed explanation of the part oxygen plays in the matter of sewage disposal is to be found in the appended reports.

These reports and the accompanying charts show the extent to which the Seekonk, Moshassuck, Woonasquatucket and Providence Rivers have fallen below the safe limit of oxygen saturation.

The examinations of the rivers carried on during 1922 were made at a time when the rivers were in a more favorable condition than normally exist in summer, owing to abnormal rainfall which kept the rivers at flood stage much of the time and thereby increased the dilution of the entering sewage and the amount of oxygen available for its purification.

Yet, even under these favorable conditions, the reports and charts show a very large part of the waters of those rivers were far below the safe limit of oxygen saturation. In many places and at many times it was found that these rivers were not only absolutely lacking in oxygen, but that they had an oxygen demand or need greater even than the full normal oxygen content of river water. In other words, the rivers at such places and times had acquired the practical aspect and quality of open sewers.

The above mentioned circumstances and conditions are pointed out at this time in order that the necessity for remedial measures may be emphasized. The volume of municipal sewage and manufacturing waste is so great that the best reasonably available systems and means should be adopted and used to relieve our over-burdened rivers.

Such studies as that made during the past summer and such similar studies as may be made in the future will serve the Board as a guide to show where improvement must be sought and what degree of

purification of municipal sewage and manufacturing waste must be accomplished in various places to remedy existing pollution; and these studies will enable the Board to forecast when and where purification or limits of pollution must be established to prevent undue pollution in the future, allowing reasonable use of the public waters by all.

Respectfully submitted,

THOMAS H. CONNOLLY,
GILES W. EASTERBROOKS,
HAROLD T. MERRIMAN.

Board of Purification of Waters.

PRELIMINARY REPORT OF AN INVESTIGATION OF THE POLLUTION OF CERTAIN RHODE ISLAND PUBLIC WATERS.

By Stephen DeM. Gage* and Phillip C. McGouldrick.**

IT has been known for many years that certain Rhode Island public waters were becoming more and more polluted and that some of these waters had already become a nuisance through the discharge into them of excessive quantities of sewage and manufacturing wastes. Until the creation of the Board of Purification of Waters, however, no systematic attempt has been made to determine the exact condition of these various waters. One of the functions of this Board is to clean up the various rivers and tidal waters of the state. In order that the Board may perform this function with justice and fairness it is essential that it should know what waters are now or are in danger of becoming unduly polluted, the sources from which pollution is coming and the amount and character of such pollution at each source, and the effect of the pollution of each body of water upon all other adjacent waters.

Early in 1922 plans were made for a thorough investigation of all the public waters of the state and active work was started in June and continued throughout the summer. It was realized at the start that to obtain the full and complete information needed would require an investigation extending over a number of years. In planning the work for 1922, therefore, it was arranged to make a general preliminary survey of as many of the various rivers, streams and tidal waters as possible and to supplement this preliminary survey by an intensive study of a few of the most seriously polluted waters. In the following report are presented certain of the data obtained in these investigations, particularly those relating to the pollution of the Moshassuck, Providence and Seekonk Rivers and of upper Narragansett Bay.

This investigation was conducted under the general direction of Stephen DeM. Gage, with Philip C. McGouldrick in charge, assisted by a field staff consisting of Kenneth V. Hill, Assistant Sanitary Engineer, Nelson M. Fuller, Assistant Biologist, Frank B. Littlefield, Assistant Chemist, and J. Albert Gage, Field Assistant. The field staff was divided into two working parties, Messrs. Hill and J. A. Gage with an automobile making studies of the inland rivers and streams while Messrs. Fuller and Littlefield with a power boat made studies of the navigable waters. The Board already had a power boat engaged in oil inspection work and the routing of this boat was so arranged that it could be used

*Sanitary Engineer of the Board. **Chemist of the Board.

at the same time for field studies. From time to time the entire staff was consolidated for concentrated studies at one point or another, and at occasional intervals men were transferred from one working party to the other in order that all members of the staff might gain a better conception of the interrelation of the results obtained in different localities. In addition to maintaining a close supervision over the details of the investigation by working at intervals with each field party, Mr. McGouldrick also conducted such chemical analyses as were made in the laboratory.

Owing to the extremely crowded conditions existing in the laboratories of the State Board of Health it was impossible to make complete chemical and bacterial analyses of any considerable number of samples, although it was fully realized that such analyses of the different public waters and of the various wastes discharged into them would have to be made before a complete working knowledge of the prevailing sanitary conditions in those waters could be obtained and the most feasible methods for remedying excessive pollution worked out. It was necessary, therefore, to confine the investigation largely to determinations of dissolved oxygen and to such other studies as could be made in the field, and to limit the laboratory work to the examination of a few samples collected in connection with concentrated studies of the more seriously polluted waters. In addition a few studies were made of the types of microscopical organisms present in certain waters and in the muds beneath these waters. Determinations of the location, extent and character of deposits of sludge and float measurements to establish the direction of currents and the probable carriage of sewage and manufacturing wastes have also been started.

The summer of 1922 was one of unusually high rainfall and not only were there many days when the field parties could not work outside, but frequent changes in the previously arranged sampling schedules were required, both of which seriously interferred with the progress of the investigation. As the rivers were in flood much of the time dilution was much greater than usual and for this reason pollution was undoubtedly less pronounced than would ordinarily be the case during the summer season. Every effort was made to obtain representative results, but it must be borne in mind that the results presented in this report probably indicate the best summer conditions rather than those which would prevail during the average summer with low rainfall.

Previous Investigations.

The nuisance ensuing from the pollution of the Providence River and its tributaries has been a cause of complaint for more than sixty years. As far back as 1855, in a report[1] on the causes of cholera in Providence during the previous year, Dr. Edwin M. Snow stated: "With regard to the deaths in the neighborhood of the canal (Moshassuck River) I answer unhesitatingly that the canal itself was the cause. . . . The same place was one of the principal foci of the disease in 1849. . . . The condition of the canal during the summer was such that the common sense of the whole city regarded it as a great nuisance. It was as filthy as any common sewer, and the stench arising from it at times per-

[1]City Document No. 5, 1854–55.

vaded the whole neighborhood." Although this report was written almost seventy years ago the character of this stream today is not far different, although the causes of its unsavory condition have changed somewhat since that time. In 1876 vigorous agitation for betterment of these conditions caused the board of aldermen to instruct the superintendent of health, Dr. Snow, to ascertain if the pollution of the waters of the stream was injurious to the health of the city. In his report,[1] in addition to reaffirming his earlier statements Dr. Snow adds "The water of the river is polluted and rendered exceedingly foul and offensive before it reaches the limits of the city. . . . It is certain that much filth is turned into the river from the city, and it must be still more filthy when it reaches the harbor. The water is, however, so very foul before it reaches the city that I doubt if it is made any more dangerous to the public health by the filth it receives in the city." In this report the principal sources of pollution outside the city limits are listed and chemical analyses of samples of the water at different points are given. During the next few years agitation for improvement was practically continuous and investigations and reports on the subject followed one another in rapid succession.[2] In 1884, Mr. Samuel M. Gray, then city engineer, presented plans[3] for diversion of all sewage and manufacturing wastes of the city to Fields Point with treatment by chemical precipitation. In July, 1887, this proposed plan was adopted by the city council but it was not until February, 1889, that construction was ordered.

While the completion of intercepting sewers and purification works removed the major sources of pollution within the City of Providence, the Moshassuck still continued to serve as a public sewer for manufacturing plants in Pawtucket and Lincoln, and complaints of nuisance in the summer still continued. In 1906 and 1907 a joint investigation of the conditions of the Moshassuck, Woonasquatucket and Providence Rivers was made by the State Board of Health and the U. S. Geological Survey. This investigation was complete and exhaustive and included not only examinations of the river waters and determinations of the amount and character of the pollution discharged into the river at various points, but also included experiments with methods for the purification of the wastes from the different industries which were contributing to the pollution. The results of the studies of the pollution of the rivers were published in a special report of the State Board of Health for 1908 and the experiments on purification of factory wastes were published in 1909 as Water Supply Bulletin No. 235 of the U. S. Geological Survey.

In 1914 the cities of Providence and Pawtucket appointed a joint commission to improve conditions in the Moshassuck River. Working in close coöperation these cities deepened and straightened the channel of the river, drained much of the swamp land through which it flowed, removed certain dams to provide greater fall and increased velocity in the improved channel, and diverted the wastes from a number of industries located along the shores to the city sewers. In addition the City of Providence also expended considerable money in removing deposits of sludge from the bed of the Woonasquatucket and the upper part of the Providence River, in order to reduce the nuisance arising from putrefactive

[1]City Document No. 33, 1877.
[2]See City Documents Nos. 30, 1878; No. 24, 1882; Nos. 21 and 24, 1883.
[3]City Documents No. 25, 1884.

conditions. To a considerable extent the joint work of these two cities reduced the nuisance arising from the stagnant conditions in the Moshassuck, but as a number of major sources of pollution were not eliminated the improvement in the lower part of this river and in the Providence river was much less than the public had been led to expect. There was one effect of the improvement of the Moshassuck, however, which was not foreseen. Large amounts of suspended organic matters which had hitherto been deposited and destroyed in the stagnant sections of the river were now carried down and precipitated in the upper part of the Providence River, thereby increasing the pollution and the nuisance at that point.

In 1914 the U. S. Public Health Service started an investigation into the general sanitary condition of northern coastal waters, and during 1915 a working party spent the greater part of the summer in Rhode Island waters. In this investigation studies were made of the dissolved oxygen and bacterial content of the water and of the pollution of oysters and other shellfish. Unfortunately these studies and the preparation of the results for publication were interrupted by the war and the information obtained is not available.

In 1918 an investigation was made by the Commissioners of Shell Fisheries of the pollution of upper Narragansett Bay. This investigation included determinations of dissolved oxygen on top and bottom samples at ten different sampling stations on three separate dates in midsummer, together with chemical and bacterial examinations of samples of the water. The following quotations from the report* on that investigation indicate the conditions found in the upper bay at that time:

"On August 11, when the poorest conditions were found, the water collected from both top and bottom at seven of our sampling stations contained less than this amount (fifty per cent.) of oxygen. On July 29, oxygen values below the safe limit were found in bottom samples collected from Stations 2, 4, 5 and 6, and on August 26, the oxygen was below the safe limit at both top and bottom at station 1, 2, 3 and 4, and at the bottom at stations 5 and 6. It is evident from these results that during the past summer the pollution in the greater portion of that part of the bay lying between Field's Point and Conimicut exceeded the safe limit at times. In fact, on August 12, water from the bottom at station 2 was entirely devoid of oxygen and that from the bottom at station 4 contained only about 10% of the amount of oxygen required for saturation. While we may not know definitely how much or how little oxygen is necessary to support shellfish life, it is certain that shellfish could not live at station 2 under these conditions and it is probable that they could not live at station 4. . . . Determinations of free and albuminoid ammonia in samples from nearly all of these various stations also show excessive pollution at times."

Examinations of clams and quahaugs made during this investigation showed conclusively that at that time shellfish growing in the upper part of Narragansett Bay were so badly polluted that they were unfit for use as food. As a result, the Commissioners of Shell Fisheries prohibited the taking of shellfish for food from the waters or shores north of a line drawn east and west through Bullocks Point Light.

In addition to the published data contained in these various reports, the State Board of Health has accumulated in its files a large amount of unpublished data

*Annual Report of Commissioners of Shell Fisheries for year ending December 31, 1918.

bearing on the amount and character of pollution of these and other public waters of the state. In 1913, regular monthly examinations were made of the Blackstone River at a number of carefully selected sampling points between the Massachusetts-Rhode Island line and the Seekonk River. During the years from 1914 to 1917 chemical analyses and determinations of the dissolved oxygen content were made from time to time on the waters of the Moshassuck, Woonasquatucket and Saugatucket Rivers at various points. For more than twenty years that board has also made regular monthly analyses of the effluents from sewage purification plants and of samples from a number of the rivers. These long term records are especially valuable as they permit variations due to seasonal and other causes to be determined and normal conditions established, while the results obtained in the miscellaneous studies serve as a connecting link between earlier investigations and those now in progress.

Drainage Areas of Narragansett Bay.

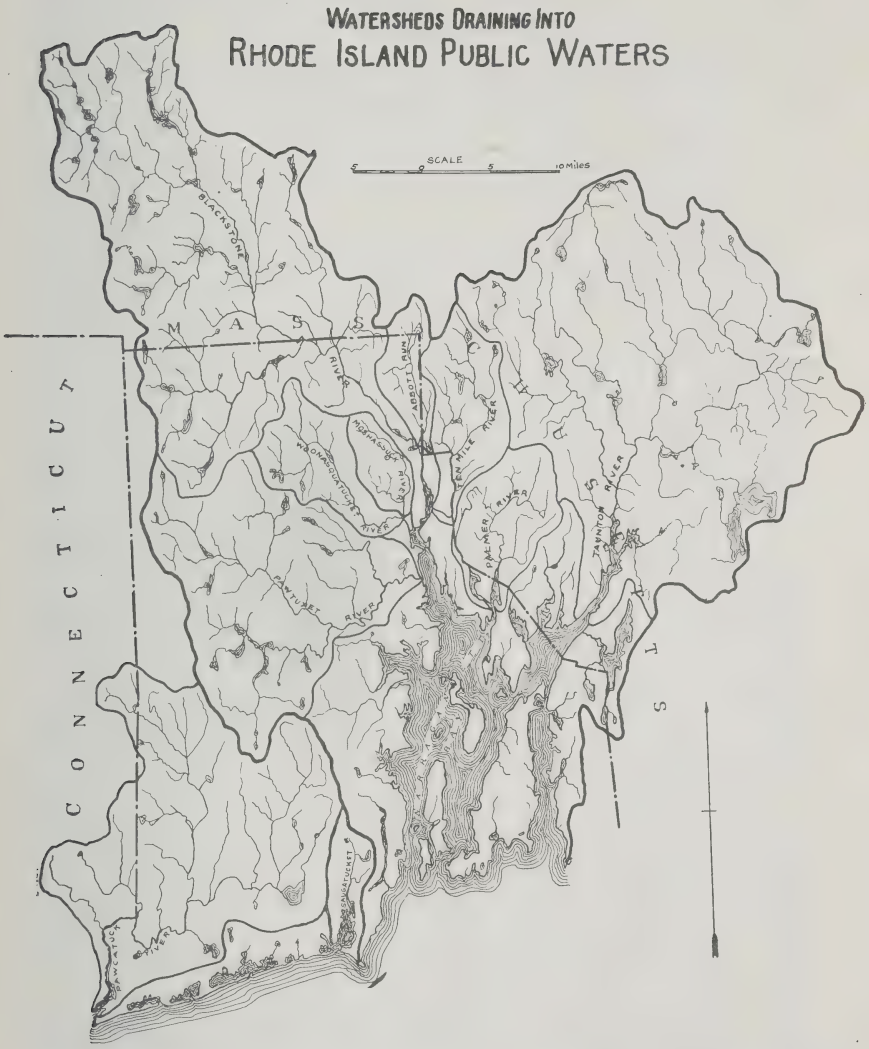
Before attempting to discuss the pollution of the public waters of Rhode Island, it may be well to outline briefly the natural drainage areas which empty into or form a part of those waters, in order that their effect upon one another as regards pollution may be clearly understood.

The main drainage systems tributary to Narragansett Bay may be divided into four general groups, those on the North discharging into the Seekonk and Providence Rivers and the upper bay, those discharging directly into the lower bay on the east side and into Greenwich Bay on the west side respectively, and those discharging into the easterly part known as Mount Hope Bay. These different drainage systems are shown on the map Fig. 1. The main outlet to the ocean for the waters from the first three systems is directly south through the east and west channels, so called, on either side of the Island of Conanicut. Mount Hope Bay lies almost entirely in Massachusetts, but the waters draining into it find their way to the ocean through Rhode Island, a part flowing south through the passage known as the Seaconnet River on the easterly side of the Island of Rhode Island, and a part flowing west directly into lower Narragansett Bay.

In the northern drainage area are included eight principal river systems, the Pawtuxet, Woonasquatucket, Moshassuck, Blackstone, Abbott Run, Ten Mile, the Warren or Palmer River system, and Hunts River. The total area drained by these rivers is about 957 square miles.

With the exception of the Palmer River which drains through the Warren River directly into the north-east section of the lower bay, of the Hunts River which enters the lower bay just south of Greenwich Bay, and of the Pawtuxet River which flows into the upper bay on the west side just below the mouth of the Providence River, and of the areas drained by small streams immediately adjacent to the shores, all of these various river systems drain into or through the Providence River.

Practically all of the drainage area of the Ten Mile River, a little more than three-fourths of the drainage area of the Blackstone River and approximately one-third the drainage area of the Abbott Run is in Massachusetts and hence outside of Rhode Island control.


WATERSHEDS DRAINING INTO
RHODE ISLAND PUBLIC WATERS
SCALE
0
5
10 miles
BLACKSTONE
RIVER
MASS.
CONNECTICUT
ABBOTT RUN
PAWTUXET
RIVER
PAWTUXET
RIVER
PAWTUXET
RIVER

The Abbott Run is controlled for water supply purposes by the City of Pawtucket. Approximately nine million gallons daily of the water flowing in this stream is taken for the water supply of Pawtucket, Central Falls and part of East Providence, and is returned to the Moshassuck, Blackstone and Seekonk Rivers as sewage.

The Ten Mile River is also used for water supply purposes by the East Providence Water Company. About two million gallons per day of water are taken from this stream by the East Providence Water Company at Hunts Mill, approximately half of which is returned to the Seekonk River as domestic sewage and the other half as bleachery and dye house wastes. Located on the drainage area of this stream are the towns of Attleboro and North Attleboro. While the municipal sewage of both of these communities is very completely purified the river receives considerable amounts of manufacturing wastes from industrial plants in these towns and from a large bleachery and dye works located in Pawtucket.

By far the largest and most important of the watersheds draining into the northern portion of Narragansett Bay is that of the Blackstone River, with a total area of some 488 sq. mi. discharging through the Seekonk into the Providence River. Included in this drainage area are the cities of Pawtucket, Central Falls and Woonsocket in Rhode Island, and Worcester, Mass., besides numerous smaller communities. The river being the natural outlet for domestic sewage and manufactural wastes receives a considerable amount of pollution from these sources, but as the river is of good size and the points of pollution in many cases are some distance apart, there is considerable opportunity for self purification of the waters before they are discharged into the Seekonk.

The Moshassuck is a comparatively small stream, which serves as the outlet for the wastes from a number of large textile plants and for the sewage of a part of the City of Central Falls. This river at the present time is the most grossly polluted of any of our Rhode Island public waters.

The Woonasquatucket River is also used throughout its length for manufacturing purposes. The communities along this river are small and unsewered, however, and the amounts of manufacturing wastes discharged into this stream are relatively slight.

The Pawtuxet River entering on the west side of the upper bay is lined throughout the greater part of its length with prosperous manufacturing communities. At Pettaconsett about four miles up the river some 25 million gallons per day are diverted from this stream for water supply purposes by the City of Providence and the most of this water is returned to lower end of the Providence River as sewage. No domestic sewage is permitted to enter the Pawtuxet above the water works intake but appreciable amounts of manufacturing wastes are discharged into it throughout its length from textile and similar industries.

The principal river system on the east side of the lower bay is that of the Palmer and Barrington Rivers which discharge through the tidal stream called the Warren River. The main drainage area of these streams is sparsely settled, except near the lower end on the Warren River. A portion of the watershed of the Palmer River is impounded for water supply purposes by the Bristol and Warren Water Company. The sewage from the Town of Warren is discharged into the Warren River about two miles above the point where that river empties

into the bay. In this drainage section must also be included Bristol Harbor, which receives the sewage from the Town of Bristol. This harbor is entirely tidal and has only a small local watershed.

On the west side of the lower bay a number of small streams drain into Greenwich Bay. All of these are relatively clean with the exception of the small stream known as the Apponaug River which is grossly polluted by bleachery and dye house wastes. Greenwich Bay also receives the sewage from the public sewers of the Village of East Greenwich, but the amount of this is so small that it has little effect on the waters of the bay. In this drainage area is also included the Hunts River, which is used in part for water supply purposes by the East Greenwich Water Company.

The drainage area of Mount Hope Bay includes the Kickemuit, Coles and Lee's River, which enter from the north, and the Taunton River system which enters from the east. Almost the entire drainage area of these rivers is located in Massachusetts and is therefore outside Rhode Island control. Practically the entire dry weather flow of the Kickemuit is diverted for water supply purposes by the Bristol and Warren Water Company, and for the most part is discharged into lower Narragansett Bay as sewage from the towns of Warren and Bristol. The Coles and Lee's Rivers are small and their watersheds are practically uninhabited except by summer colonies located near the mouth.

The principal drainage area discharging into Mount Hope Bay is that of the Taunton River and its tributaries. In this watershed, the City of Brockton operates disposal works for the purification of its sewage, but large amounts of domestic sewage and manufacturing wastes are discharged unpurified from the Cities of Fall River and Taunton and from certain of the towns. As stated previously this river system and Mount Hope Bay into which it drains are located in another state, but the only outlet for the waters and their burden of pollution is through Rhode Island.

In addition to the watersheds draining into Narragansett Bay there are two separate river systems draining the southern portion of the state, namely, the Saugatucket which flows into Point Judith Pond, and the Pawcatuck which empties into Little Narragansett Bay at the boundary between Rhode Island and Connecticut. A portion of the watershed of the Saugatucket is used for water supply purposes by the Wakefield Water Company and a part of the waters so diverted is discharged into the ocean as sewage from the Town of Narragansett. On the lower end of this river are located the Villages of Wakefield and Peacedale from which a considerable amount of manufacturing waste and some sewage from private sewers finds its way into the stream. The drainage area of the Pawcatuck and its tributaries is largely farming country, but includes also a number of small manufacturing villages from which more or less manufacturing waste enters the stream.

Stream flow measurements have been made on the Abbott Run by the City of Pawtucket regularly since 1917. The average flow of this stream is about .94 million gallons per 24 hours per square mile of watershed. Flow measurements on the north branch of the Pawtuxet River at Fiskeville have been made by the Providence Water Supply Board since 1916. The average flow at this point is about 1.35 million gallons per 24 hours per square mile of watershed. A few measurements have also been made on the Ten Mile, on the Moshassuck

and at different points on the Blackstone but these measurements were either not consecutive or were not continued for sufficiently long periods to show the normal flow of these streams. During the past year gauges have been installed at Lonsdale on the Blackstone and at Hunts Mills on the Ten Mile and river heights are being recorded regularly. So far as we have been able to determine no measurements of other Rhode Island streams have been made. The watershed of the various areas draining into Rhode Island tidal waters together with the estimated population included therein are shown in Table No. 1.

TABLE NO. 1.

DATA OF DRAINAGE AREAS TRIBUTARY TO RHODE ISLAND PUBLIC WATERS.

WATERSHED.	Area of Watershed* square miles.	Per cent Watershed outside of R. I.	Estimated Population on Watershed.	
			Total.	per square mile.
Blackstone River	487.9	71	366,700	750
Ten Mile River	56.5	89	29,000	515
Moshassuck River	22.1	0	24,000	1,090
Woonasquatucket River	55.5	0	7,200	130
Pawtuxet River	237.7	0	49,600	210
Hunts River	17.2	0	3,300	190
Apponaug River	7.6	0	1,200	160
Palmer River**	69.0	82	11,700	170
Taunton River	530.3	100	161,100	300
Saugautucket River	17.0	0	5,100	300
Pawcatuck River	312.9	19	75,700	240
Unclassified Local Drainage to Narragansett Bay	118.1	32	85,200	720
Unclassified Local Drainage to Long Island Sound	49.1	0	1,100	20

*Including water surface.
**Including Barrington and Warren Rivers.

In closing this chapter it may be of interest to mention that the total land area of the state is 1053 square miles, of which 265 square miles or slightly over one-fourth is included in the watersheds of various Rhode Island public water supplies. In addition the watersheds of these Rhode Island water supplies include about 90 square miles in Massachusetts from which all or part of the water diverted is discharged as sewage into Rhode Island waters. The total area of Narragansett Bay and other Rhode Island tidal waters is about 197 square miles or about sixteen per cent. of the entire area of the state. Rhode Island is the most densely populated state in the union with an average population of 573 persons per square mile of land area.

Dissolved Oxygen and its Relation to Pollution and Self Purification of Water.

The major portion of our studies have been devoted to determinations of the amount of dissolved oxygen in the water at different points. Before attempting to set forth the results of these studies it seems advisable to briefly describe the part which dissolved oxygen plays in the purification of polluting matters and its significance in the stream.

The vegetable and animal matters in sewage and manufacturing wastes, organic matters as they are termed, have a highly complex chemical structure. Nature has provided means for disposing of these waste matters by gradually breaking them down into simpler bodies and then converting them into inert mineral matters through the action of bacteria and other biologic organisms. When this process of decomposition takes place in the presence of air or oxygen, that is by oxidation, the process continues throughout without nuisance. On the other hand when decomposition takes place in the absence of air, or when the amount of oxygen is insufficient, putrefaction occurs and offensive odors, etc. are produced. These various processes may go on in a sewage plant, or they may take place in a stream or other body of water or elsewhere. The relation of the dissolved oxygen content of any body of water to the amount of oxygen required for complete oxidation of the pollution discharged into it is, therefore, of the utmost importance if that body of water is to be prevented from becoming a nuisance. The question is one of supply and demand, of balancing the total available oxygen carried by the water against the oxygen demand of the various organic matters which constitute the pollution. It is evident that there is a limit to the amount of sewage or manufacturing wastes which may be absorbed by any body of water and purified by oxidation, and that if this limit is greatly exceeded putrefaction and offensive conditions must result.

There are several sources of dissolved oxygen in any body of water. Some oxygen is dissolved at the surface of the water from contact with the air. Aëration may be increased by wind blowing upon the surface, agitating the water into riplets and waves. In this case the increase in dissolved oxygen depends upon the velocity of the wind. On the other hand, a film of oil on the surface forms a seal which prevents the absorption of oxygen from the air into the water, and also greatly reduces the formation of waves and ripples by wind action. Water flowing over a dam or in a shallow layer over a wier or over a rough stream bed also receives a considerable amount of aëration. The dissolved oxygen content of water is also increased by the photo-synthesis of rapidly growing algæ and other aquatic plants.

The dissolved oxygen content of water varies with the temperature of the water and with the barometric pressure. At a temperature just above freezing fresh water will absorb about fourteen parts per million of oxygen, while at ordinary summer temperature the amount of oxygen which the water can carry is reduced to about nine parts, or less than two-thirds of the amount which is available under winter conditions. Biological life through whose action the decomposition of sewage and other organic matters is accomplished is, however, much more active in warm weather than in cold, with the result that the greatest demand for oxygen comes at the time when the available supply is the lowest. The amount of dissolved oxygen in water in the summer also varies to a certain

extent with the weather, the oxygen content increasing on bright sunshiny days, probably due to more rapid photo-synthesis by algæ and other aquatic plants.

The question of whether the water is fresh or salt is also an important consideration. Sea water will absorb and carry only about four-fifths as much oxygen as fresh water, and the amount of sewage which a body of salt water is capable of absorbing without creating a nuisance is therefore proportionately less. In addition when putrefactive conditions occur in salt water they are likely to be much more offensive than is the case in fresh water owing to the breaking down of the sulphates of the sea water and the liberation of excessive amounts of malodorous Hydrogen Sulfide gas.

The dissolved oxygen content of a body of water may also vary considerably at different depths. In a body of stagnant water it is generally the case that the water nearest the surface contains a larger amount of dissolved oxygen. If this body of water has received pollution and the bottom is covered with a deposit of decomposing organic matters, it may readily happen that while the upper layers of the water contain dissolved oxygen and the process of oxidation may be taking place, at the bottom the breaking down of the deposited organic matters may proceed so rapidly that all oxygen in the lower strata of the water may be used up. In this connection also the salinity of the water plays an important part. The finely divided solids which constitute a considerable proportion of the putrescible organic matters in sewage and many manufacturing wastes are quite largely carried in suspension in fresh water and are thus brought into intimate contact with all the available oxygen of that water. When such sewages and wastes, or when fresh water containing any considerable proportion of them, are discharged into salt water, the sudden change in salinity causes a rapid precipitation of the suspended matters, with the result that deposits of a highly putrescible nature are formed on the bottom where the supply of available oxygen is lowest.

The opinions of sanitary engineers vary somewhat as to the safe limit of oxygen which must be carried in a stream or other body of water in order to ensure that offensive conditions will not be likely to occur. Studies in New York Harbor and in many rivers indicate that when the dissolved oxygen content falls below 50 per cent. of that required for saturation offensive conditions are likely to occur either temporarily or permanently. It is usually assumed, therefore, that 50 per cent. of saturation is the safety limit for the amount of dissolved oxygen which any body of polluted water must carry in order to remain non-offensive during the summer months. In the various graphs given in this report, those portions of the dissolved oxygen curves which are below the 50 per cent. line have been cross hatched to indicate that the amount of available oxygen was below the safe limit.

The Moshassuck River.

The Moshassuck River is a small stream approximately six miles long, rising in the Town of Lincoln and flowing south through the cities of Central Falls and Pawtucket to Providence where it joins with the Woonasquatucket River and becomes what is known as the Providence River.

The total area of the Moshassuck River watershed is 21.5 square miles, of which 10.05 sq. mi. is included in the drainage area of the West River, its chief tribu-

tary. From a few stream flow measurements and computations made from the data of yearly precipitation and the area of the watershed, the estimated normal flow is about 20 million gallons per day, 9.5 million gallons per day of which are contributed by the West River. At no point in its course does the river have a greater depth than three feet, nor a greater width than thirty feet, and velocity never exceeds three feet per second. The river has few opportunities for aëration, there being only five small dams in its whole course, the largest fall not exceeding five feet.

Sources of Pollution: Above Sayles Pond there are no sources of pollution. On leaving Sayles Pond practically the entire flow of the river passes through the plants of the Sayles Finishing Company at Saylesville and is used for industrial purposes. Here the river receives its initial and major pollution. It is estimated that the total volume of bleachery and dye house works, domestic sewage, etc. discharged from this plant is about 6 million gallons daily, of which about 2 million gallons receive treatment by sedimentation in settling tanks.

Just above Weeden Street Bridge the river is joined by the Central Falls Brook which brings down the sewage from the Moshassuck Valley drainage district of the City of Central Falls. This sewage is treated in a small plant consisting of an Imhoff tank and a sprinkling filter. The brook is shallow, with little fall, flowing through a swamp for nearly a mile before it empties into the river. The normal flow of this brook at its outlet is about one-half million gallons daily. The average volume of sewage treated at the disposal plant is about 170,000 gallons daily. The treated sewage is seldom of stable character and usually has a high oxygen demand. Conditions in the brook are entirely favorable for putrefaction, as the water is usually devoid of oxygen. The effect of the discharge of this highly putrescible sewage into the river not only adds to the pollution but apparently brings into the river immense numbers of putrefactive bacteria which attack the starches, gums, etc. which have been discharged from the Sayles Plants and aid in causing a very offensive putrefaction both in the water and in the deposits upon the bed of the stream.

At the Lorraine dam about 200 yards below Weeden Street Bridge the river receives a slight aëration and agitation. Dividing here, part of the stream flows around the Lorraine Mill, and part is taken through the mill for power and manufacturing purposes. In the yard of the Lorraine Mill above Mineral Spring Avenue there are three sources of pollution, namely: a 24 inch pipe which discharges dye house wastes, and two 12 inch pipes which discharge bleachery wastes. The exact amount of pollution discharged from these three sources is not known but a conservative estimate would be that the volume is at least 2 million gallons per day. The dye house wastes discharged at this point badly discolor the river.

At Mineral Spring Avenue, the dividing line between the worsted and woolen and the cotton divisions of the Lorraine Manufacturing Company, two 30 inch storm water drains discharge into the river. Immediately above Grotto Avenue there is an outlet from the dye house of the cotton division which discharges approximately 0.5 million gallons per day of wastes. At this point, also there is a dead end-channel which receives the waste liquors from the wool grease recovery plant of the Lorraine Manufacturing Company. The water in this channel is stagnant and was in a high state of putrefaction during the greater

part of the summer. Although the discharge from this channel into the river is usually not more than 25,000 to 50,000 gallons per day, this discharge is highly charged with organic matter of a very offensive character.

A few years ago a partial separation of the Lorraine Mill wastes was made and certain of the more highly organic liquors were discharged into a sump from which they were pumped into the Pawtucket sewers. Owing to poor screening of the wastes much trouble has been experienced in keeping these pumps in operation. From personal observation it is known that the pumps were not in operation during the summer although they were found in operation on October 20, 1922.

Below Grotto Avenue the river takes a winding course through a swampy area for a distance of approximately a mile to Cemetery Street. Owing to various obstructions the level of the water in this swamp remains fairly constant during the day flow, while septic action goes on very rapidly. At the lower end of this swampy area a 24 inch cast iron pipe discharges wastes from the Mason Company into a shallow lagoon which overflows into the river. The amount of pollution entering the river at this point is approximately 250,000 gallons per day.

Immediately below the discharge from the R. D. Mason Company there is a 54 inch storm overflow from the Pawtucket sewer system which operates automatically when the flow of sewage exceeds 1.8 million gallons per day.

Dissolved Oxygen Studies. Studies of the dissolved oxygen content of the Moshassuck River were made on fourteen different dates during the summer. The survey included seventeen sampling stations, extending from the pond above the Sayles Finishing Company, to the Point Street Bridge on the Providence River. The results of dissolved oxygen determinations at these various points together with the relative location of the sampling stations are shown graphically in Fig. 2, the portions of the river where the oxygen was below the safe limit being cross hatched.

The water as it leaves Sayles Pond is clear and practically free from evidence of pollution. The dissolved oxygen content at this sampling station was near the saturation point at all times during the summer. Immediately below the Sayles Finishing Plant the river is very turbid, somewhat discolored and there is a decided reduction in dissolved oxygen. The effect of the discharge from the settling tanks is shown by an increase in the turbidity and also a drop in the dissolved oxygen curves. At Weeden Street Bridge the influence of the entrance of the grossly polluted waters of the Central Falls Brook is evidenced by a further decrease in dissolved oxygen and by the appearance of "sleek" in the river. Just below the Lorraine Dam the river generally shows the effect of reaëration by a slight increase in dissolved oxygen.

The effect of the pollution received from the various sources at the Lorraine Plant are shown in the results of dissolved oxygen test at Grotto Avenue. Except in the case of samples collected on Sunday and Monday the river at this point was completely devoid of oxygen at all times throughout the summer.

Between Grotto Avenue and Cemetery Street the river is stagnant and considerable putrefaction occurs. At Cemetery Street the water always has a pronounced odor of Hydrogen Sulfide and not only contains no dissolved oxygen but has a high oxygen demand. The river at this point has a distinct black color. From Cemetery Street to Smithfield Avenue, the next sampling station,

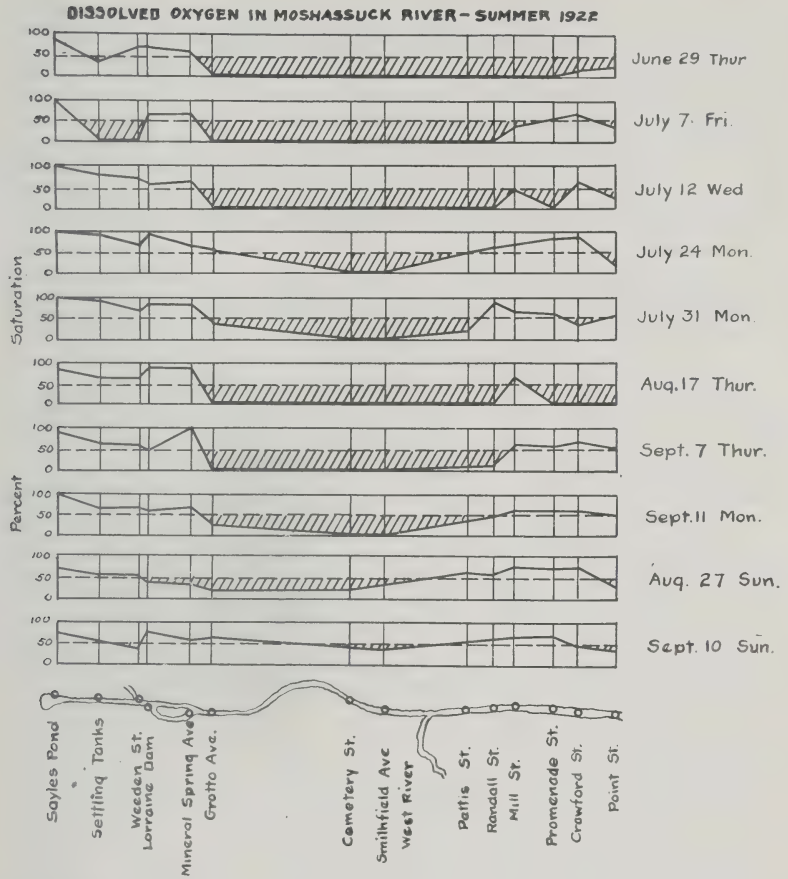


FIG. 2. Graph showing dissolved oxygen content of Moshassuck River at different points during the summer of 1922. Shaded areas deficient in oxygen.

the river flows through the swamp on the west of the North Burial Ground maintaining the same characteristics of lack of oxygen, of odor and of color. The West River coming in just above Livingstone Street furnishes a dilution of approximately one-half of the total stream flow with water practically saturated with oxygen. The amount of available oxygen brought in by the West River, however, is not generally sufficient to compensate for the oxygen demand of the waters of the main stream, and from this point down to its junction with the Woonasquatucket the dissolved oxygen values obtained were far below the safe limit most of the time.

It is especially to be noted that the section of the river which was deficient in oxygen content was much smaller on Sundays than later in the week, and this improvement can only be attributed to the comparative freedom from manufacturing pollution. On Mondays, also, as indicated by the graphs, the water in the river was of better quality than later in the week when the effect of manufactural pollution becomes more and more marked.

Throughout its entire course from the Sayles Finishing Plant to Promenade Street the waters of the Moshassuck have a characteristic milky turbidity, and at the confluence with the Woonasquatucket a distinct line of demarcation between the waters of the two streams can always be observed.

In considering the extent of pollution of this stream and of the effect of putrefaction of organic matters discharged into it, it must be remembered that the summer of 1922 was one of exceptionally high rainfall, and that for this reason the river was undoubtedly in a less offensive condition than would have been the case during a summer of normal or low rainfall.

Concentrated Studies. After it had been definitely determined that the greater part of the pollution was coming into the Moshassuck River between the Sayles Pond and Grotto Avenue it was decided to make concentrated studies of this part of the river. For this purpose five men were distributed at different points to make hourly determinations of dissolved oxygen and to collect composite hourly samples for chemical and bacterial examination. At the same time flow measurements were made of the river, of the Central Falls Brook, and of the discharge of the Sayles Settling Tanks and of the Central Falls Sewage Disposal Plant. The sampling stations were located as follows:

Moshassuck at Sayles Pond.
Moshassuck above outfall Sayles Settling Tanks.
Moshassuck between outfall of Sayles tanks and Central Falls Brook.
Moshassuck at Lorraine Dam.
Moshassuck at Grotto Avenue.
Central Falls Brook above city sewage plant.
Central Falls Brook below city sewage plant.
Central Falls Brook at entrance to Moshassuck.
Effluent from Sayles Settling Tanks.
Effluent from Central Falls Sewage Disposal Plant.

During the first of these studies, on August 2, 1922, it began to rain about 12:30, 1.1 inches of rain falling between 12:30 and 5:30. Flow in the channel at Central Falls Brook increased from 0.75 million gallons per day at 9:30 A. M. to 2 million gallons per day at 2:30 P. M. or about 2.7 times the normal flow, and the flow in the Moshassuck increased about 7 million gallons per day. The results on this date are therefore affected by the increased dilution due to the rise in the river, and also by the fact that during the heavier portion of rainfall the Central Falls sewage was by-passed directly to the brook without treatment. A second concentrated study of this section of the river, made on August 22, represents more nearly normal summer condition of the river. The dissolved oxygen results obtained in these two series are shown graphically in Fig. 3 and the average chemical results are shown in tables Nos. 2 and 3, and on the graph in Fig. 4.

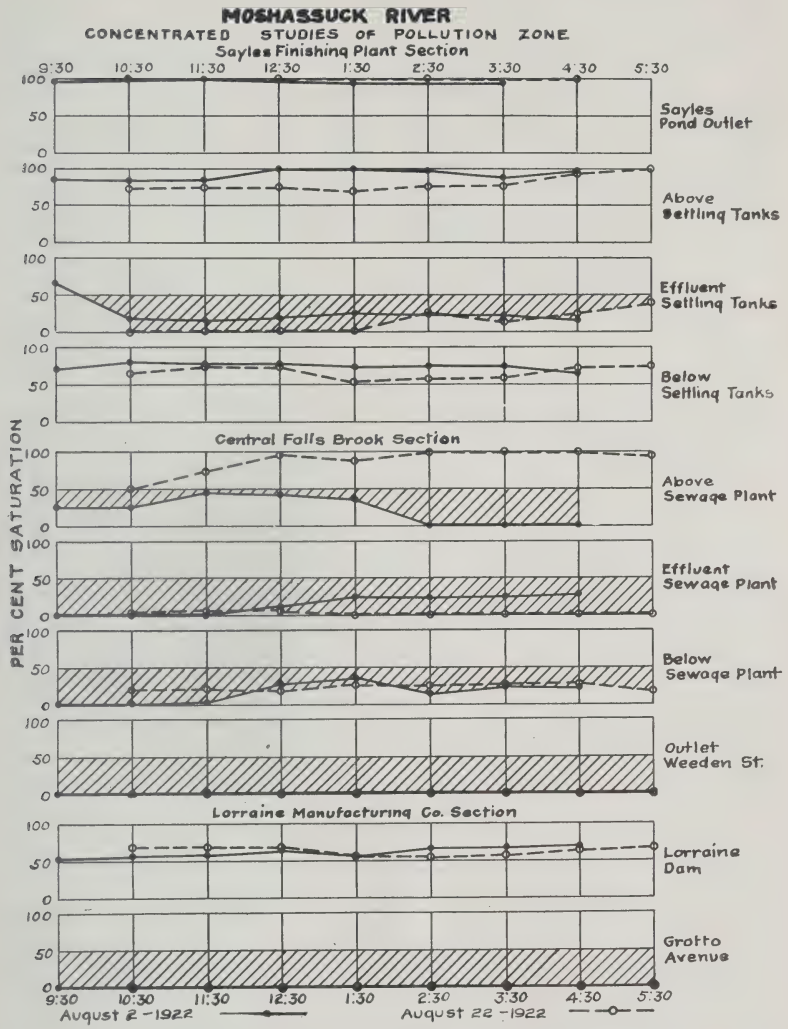


FIG. 3.—Graph showing hourly variation in Dissolved Oxygen of various points in the Moshassuck River pollution zone on August 2, 1922.

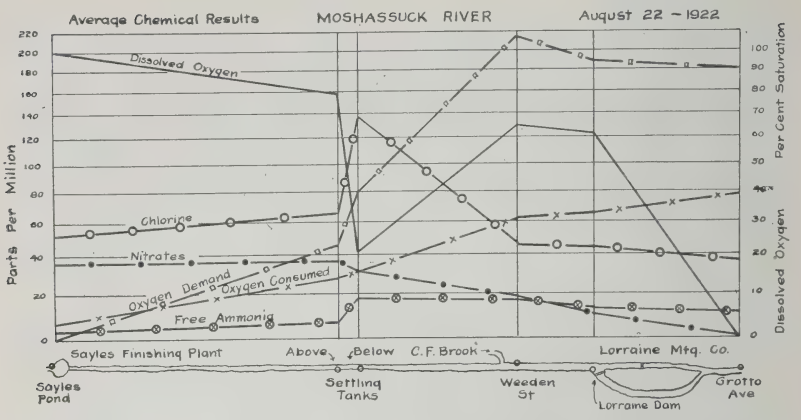


FIG. 4.—Graph showing variation in chemical quality of water of Moshassuck River at different points on August 22, 1922. Dissolved oxygen expressed as per cent saturation, other results as parts per million.

At the outlet of Sayles Pond the river was practically saturated with oxygen on both dates. Below the point of discharge of untreated wastes from the Sayles Plant there was a reduction in oxygen content in the forenoon amounting to about 17 per cent. on August 2 and to about 30 per cent. on August 22. On both dates, however, a rise in the oxygen curve was observed later in the day. The effluent from the Sayles settling tanks flows over a wier in a thin film and considerable opportunity for aëration is thus afforded. At its point of discharge into the river there is also considerable agitation and aëration but fair samples could not be obtained to show this latter effect. Just before its final discharge this effluent contained oxygen ranging from 16 to 66 per cent. throughout the first day and during the later afternoon of the second day, but was devoid of oxygen during the first four hours it was under observation on the second day. The general effect of the entrance of this strong, partly treated waste is to be observed by a still further reduction in the oxygen content of the river below the outfall of the settling tanks.

In the Central Falls Brook at the station above the outfall from the sewage plant on August 2 oxygen values increased from 24 per cent. to 45 per cent. during the first three hours, then began to decrease after rain began to fall and by mid-afternoon dropped sharply to zero. On August 22 on the other hand the trend of the oxygen curve was upward with practical saturation during the afternoon. At the station below the sewage outfall oxygen values were below the safety line throughout both series. The effluent from the sewage plant was practically devoid of oxygen throughout the series of August 22 and during the morning hours on August 2. The effect of rainfall and the by-passing of the sewage around the sewage plant was to cause an increase in the oxygen content of the brook below the outfall during the afternoon of August 2.

At the Lorraine Dam, below the confluence of the Central Falls Brook and the Moshassuck, the oxygen values fluctuated between 52 and 69 per cent. saturation, the range being similar on both dates. At Grotto Avenue, however, after receiving the wastes from the Lorraine Mills all samples during both series were devoid of oxygen.

The results of chemical analyses also furnish much information as to the changing condition of the river waters at these different sampling points. In contrast to the decrease in dissolved oxygen, there was an increase in the oxygen demand of the river between Sayles Pond and Grotto Avenue, the maximum being observed at the station between the Sayles settling tanks outfall and Weeden Street. There is a gradual decrease of suspended solids and a slight increase in soluble solids as we proceed down stream. Increase in soluble solids may be due in part to liquefaction in the Sayles tanks and in the Central Falls Brook; there is also addition of some suspended solids at the Lorraine Manufacturing Company.

Oxygen consumed is an indication of the amount of carbonacious matter, such as starch and similar materials, and the rise in oxygen consumed immediately below the outfall of the Sayles tanks and the discharge pipes of the Lorraine Plant were undoubtedly due to the large amounts of starchy matter, etc. being discharged into the river at these points. An increase in free and albuminoid ammonia is also to be noted at these two points. Except for an increase in chlorine and in free ammonia, any effect on the river from the entrance of the Central Falls sewage is almost entirely obscured by the mass pollution received above.

As will be seen from the figures in the table No. 4 the bacterial counts on samples collected in both of these studies varied considerably from station to station. A reduction in bacteria will be observed between the Sayles Pond and the outfall of the Sayles settling tanks, probably due to the disinfecting effect of the bleachery wastes. Liquefaction taking place in the settling tanks increases the bacterial counts, but the effluent when it reaches the river again receives the sterilizing effect of the chlorine and the counts decrease. At the Lorraine Dam the bacterial count shows a slight increase due to the influence of the Central Falls Brook. The 37 degree counts are very high at Grotto Avenue probably because of the fresh domestic sewage pollution received at this point.

Conclusions from Moshassuck River Studies: From observations made throughout the summer, it has been found that the Moshassuck River is receiving a volume of pollution daily (excepting Sundays) amounting to more than one-half the total stream flow, all of which enters the river in a stretch of about 2.5 miles below Sayles Pond. During more than one-half of its flow the river contains practically no dissolved oxygen, the region of no oxygen being immediately below the sources of major pollution.

It is evident from the statements in the previous pages that not only is the Sayles Finishing Plant the first point of pollution of the Moshassuck River but that the wastes discharged from this plant constitute the larger and most serious part of the pollution entering the stream.

Authorities on sewage disposal state various safe limits for sewage disposal by dilution, varying from 3.3 to 7 cubic feet per second per 1,000 population, depending upon the character of the sewage and upon the use to be made of the waters down stream. Massachusetts practice is to require a stream flow of 6

TABLE NO. 2.

AVERAGE OF CHEMICAL ANALYSES OF SAMPLES COLLECTED DURING CONCENTRATED STUDY OF MOSHASSUCK RIVER ON AUGUST 2, 1922.

(Parts per million)

	Oxygen Demand.	Free Ammonia	Albuminoid Ammonia.	Nitrate.	Nitrite.	Chlorine.	Oxygen Consumed.	Total Solids.
Moshassuck River								
at Sayles Pond	22	0.5	1.0	0.6	15.7	14.2	33.2	128
above Sayles Tanks	54	1.5	3.5	0.1	15.8	70.0	112.0	418
below Sayles Tanks	.....	12.0	1.8	120.0	0.0	90.0	69.8	686
at Lorraine Dam	.....	0.5	1.6	32.5	0.0	61.0	50.4	552
at Grotto Avenue	74	2.2	2.8	6.3	0.0	61.0	106.8	804
Central Falls Brook								
above Sewage Plant	74	5.9	1.6	22.5	15.1	80.0	21.2	376
below Sewage Plant	130	17.3	6.1	22.5	0.0	126.4	49.0	538
at entrance to river	95.2	12.0	1.6	14.0	10.2	106.0	23.6	440
Effluent Sayles Settling Tanks	.....	1.4	3.4	120.0	0.0	68.4	112.0	1152
Effluent Central Falls Sewage Plant	306	38.6	5.4	6.0	176.0	178.0	56.0	632

TABLE NO. 3.

AVERAGE OF CHEMICAL ANALYSES OF SAMPLES COLLECTED DURING CONCENTRATED STUDY OF MOSHASSUCK RIVER ON AUGUST 22, 1922.

(Parts per million)

	Oxygen Demand.	Free Ammonia.	Albuminoid Ammonia.	Nitrate.	Nitrite.	Chlorine.	Oxygen Consumed.	Total Solids.
Moshassuck River								
at Sayles Pond	.....	0.1	0.3	.....	.....	66.8	4.8	226
above Sayles Tanks	23	0.3	0.5	45.9	2.8	52.6	28.2	490
below Sayles Tanks	181	0.8	2.5	9.5	18.0	46.0	62.0	522
at Lorraine Dam	187	0.6	1.4	33.7	6.0	46.0	69.2	578
at Grotto Avenue	161	0.6	2.2	27.1	2.6	38.0	78.0	650
Central Falls Brook								
above Sewage Plant	55	2.4	1.2	90.0	0.2	40.0	7.0	286
below Sewage Plant	103	35.4	7.1	211.0	0.2	150.0	20.0	644
at entrance to river	48	18.6	3.7	75.0	0.1	116.0	20.4	492
Effluent Sayles Settling Tanks	80	0.8	3.2	37.0	24.0	136.0	116.0	1,236
Effluent Central Falls Sewage Plant	343	50.3	9.3	123.0	0.0	186.0	40.0	800

TABLE NO. 4.

CONCENTRATED STUDIES OF MOSHASSUCK RIVER AVERAGE BACTERIAL ANALYSES.

(Bacteria per cubic centimeter.)

	August 2, 1922.				August 22, 1922.			
	9:30 a. m.–12:30 p. m.		1:30 p. m.–4:30 p. m.		10:30 a. m.–1:30 p. m.		2:30 p. m.–5:30 p. m.	
	20° C.	37° C.	20° C.	37° C.	20° C.	37° C.	20° C.	37° C.
Moshassuck River								
at Sayles Pond	56,100	39,100	9,800	6,900	140	.....	3,000	1,010
above Sayles Tanks	1,300	700	2,000	1,100	500	2,821,000	800	*
below Sayles Tanks	1,300	700	98,000	56,000	100,000	2,650,000	80,000	49,700
at Lorraine Dam	398,000	297,000	14,100	8,600	320,000	25,480,000	215,000	240,000
at Grotto Avenue	6,048,000	3,300,000	361,000	102,000	1,000,000	19,900,000	.....	344,000
Central Falls Brook								
above Sewage Plant	11,600	4,200	479,000	358,000	15,100	28,400	972,000	1,510,000
below Sewage Plant	2,040,000	1,600,00	960,000	340,000	.....	11,550,000	1,790,000	2,100,000
at entrance to river	468,000	321,000	521,000	368,000	590,000	17,500,000	270,000	310,000
Effluent Sayles Settling Tanks	2,028,000	1,248,000	421,000	256,000	28,000	39,500,000	25,000	380,000
Effluent Central Falls Sewage Plant	3,220,000	1,980,000	1,330,000	580,000	500,000	5,950,000	.....	**

Heavy rainfall from 12:30 to 5:00.

*Less than 100. **Less than 1,000.

cubic feet per second per 1,000 population. Allowing 75 gallons of sewage per capita and assuming that the treated sewage from the Sayles settling tanks is no stronger than the average city sewage, on this basis it would be necessary to have a stream flow of 104 million gallons per day to provide adequate dilution. This dilution is by no means excessive considering the amount of pollution entering, its very easily fermenting character and the short distance the river has to flow before receiving additional pollution. In other words to care for the two million gallons of wastes now being discharged daily from the Sayles settling tanks would require about seven times the normal stream flow of the river, without taking into consideration the four million gallons of less polluted wastes which are being discharged without treatment.

Unfortunately it would not be practicable to eliminate the pollution coming from the Sayles Plants by diverting these wastes to some other point, first because there is no available large volume of water in the vicinity into which they might properly be discharged, and second because their diversion would appreciably reduce the already low stream flow. It would seem that in order to clean up the river in a reasonable degree, a much more careful separation of the offensive and non-offensive wastes must be made in the Sayles Finishing Plants, and that the offensive wastes must be much more highly purified than is now the case.

In order to properly dispose of the sewage from the Moshassuck Valley district of the City of Central Falls by dilution would require a stream flow of about 10.5 million gallons per day, or approximately two-thirds of the normal flow of the Moshassuck. Since the volume of sewage is relatively small, it could be diverted to some other outlet without appreciably affecting the flow of the Moshassuck. If discharge into the Moshassuck is to be continued it will be necessary that this sewage be very much more highly purified than can be accomplished at the present disposal plant, and also either that the brook be straightened and its velocity increased or that the highly purified effluent be conducted to the river in a pipe line.

A conservative estimate of the total volume of pollution discharged into the river from the Lorraine Plant is 2 million gallons daily. By a more careful separation of most of the offensive wastes and more highly colored dye liquors from the other relatively clear waters and the diversion of these into the Pawtucket sewers together with all domestic sewage, practically all pollution of the river from this plant could be eliminated. There is some question, however, as to the propriety of discharging the wool scouring wastes into the public sewers without more complete purification, as it is quite possible that the presence of wastes of this particular character might interfere with subsequent purification of the sewage.

The character of the various wastes produced at the R. D. Mason Plant were investigated in detail by the State Board of Health and the City of Pawtucket about seven years ago, and since that time all highly organic wastes and the stronger dye liquors, together with the domestic sewage from the plant have supposedly been diverted to the public sewers. Although the wastes now being discharged are quite highly colored, the discoloration of the river from this source is ordinarily not apparent except in the immediate vicinity of the point of discharge.

As to whether the storm overflow from the Pawtucket sewer system which enters the Moshassuck just below the R. D. Mason Plant appreciably contributes to the pollution was not determined by the results of our studies during the past summer. The assumption is that the flow of the river will have been so largely increased and the sewage itself so much diluted by storm water that the resulting discharge will not unduly increase the pollution of the stream.

The Seekonk River.

The Seekonk River is a tidal estuary forming a continuation of the Blackstone River, extending from the falls above Main Street Bridge, Pawtucket, for a distance of about 5 miles to the Providence River. The upper end of the Seekonk is locally known as the Pawtucket River, but for purposes of investigation and discussion the entire body of water has been designated as the Seekonk. It is estimated from the tidal prism that the tidal flow of this section at its junction with the Providence River is about 2.75 billion gallons per day. Except at its confluence with the Blackstone and Ten Mile Rivers the water is salt, the average being about 31 per cent. sea water. At the northerly end the Blackstone brings in the drainage from approximately 488 square miles of watershed, the oxygen content of this water being already somewhat reduced owning to pollution entering further up the river. On the east about half way between the entrance of the Blackstone and the confluence with the Providence River, the Ten Mile River discharges the fresh water collected from a drainage area of approximately 56.5 square miles which has received comparatively little pollution and is therefore of high oxygen content.

Sources of Pollution: At the head of the river within a distance of less than one-fourth mile the sewage from the public sewers of Pawtucket is discharged through four outlets, three located on the west side and one on the east side. About one-fourth mile south of the Pawtucket sewer outlets on the east side of the river is the Solway Dyeing & Textile Company whose wastes go to the river without treatment. At Phillipsdale about two miles further down on the same side of the river are located the large bleacheries and dye works of the Sayles Finishing Plants, the plant of the O'Bannon Corporation, makers of artificial leather, the wire coating mills of the American Electrical Works and the paper mills of Bird & Sons. All of these industrial plants discharge their manufacturing wastes and sewage from mill toilets into the river. Almost directly across the river from Phillipsdale is the outlet of the Butler Avenue sewer of the City of Providence. On the southerly side of India Point on the west side of the river is located the outlet of the Pitman Street sewer which serves the major portion of the thickly settled east side section of Providence, while nearby is the plant of the Colored Worsted Company from which a considerable volume of wool scouring and other wastes are discharged. On the east side of the Seekonk just north of its confluence with the Providence River are located the two outlets from public sewers of the Town of East Providence. Our investigations of the Seekonk are as yet far from complete and data relating to the volume and character of the pollution entering the river from these different sources cannot be given at the present time.

Dissolved Oxygen Studies: Our field studies of the condition of the Seekonk were almost entirely confined to determinations of dissolved oxygen. Sixteen regular sampling stations were so located as to give a representative picture of the river from its source to its mouth, and to show both the influence of the different sources of pollution and of the effect of dilution by fresh water coming in from the Ten Mile River. As in many places the river is so shallow that fair samples could not be obtained at top and bottom on all stages of the tide, these sampling stations had to be located either in the main ship channel or not far outside. Samples from these different stations at top and bottom were collected on seven different dates, the results being shown graphically in Fig. 5. In addition samples were collected at one time or another from many other points in this river in connection with special detailed studies, but discussion of these will be omitted until the entire investigation is more nearly complete.

At station 1, above the Pawtucket sewers where the influence of the relatively clean waters of the Blackstone was most marked, on July 6 the water was completely saturated with oxygen and on the other dates oxygen values ranging from 75 to 90 per cent. saturation were obtained on both top and bottom samples. At station 2. also above the sewer outlets, while the top samples all were found to contain a plentiful supply of oxygen, a deficiency of oxygen is to be observed at the bottom on three of the seven dates when samples were taken. At station 3, below the sewer outlets, on July 6, August 3 and August 8 the water at the bottom was devoid of oxygen and only on one date, July 25, is the bottom curve above the safety line. In general bottom conditions at this location are worse than at any other part of the river. The river bed is covered with a thick deposit of sewage sludge which was in an active state of putrefaction. Gas bubbles could be seen arising at all stages of the tide while the odor of Hydrogen Sulfide was usually strongly marked.

Between station 3 and the Providence River the oxygen curve for the bottom samples is far below the 50 per cent. line throughout the summer irrespective of the stage of the tide. The worst conditions at the bottom were observed during a series taken August 3 on the flood tide, when practically all bottom samples showed less than ten per cent. oxygen. In general the curves show slight increase in oxygen content at the bottom as we proceed down river, although there are some marked exceptions. For example, on July 25 the curve drops to zero at station 13 off Bucklins Island, while on the next day there is a sharp downward break in the oxygen curve at the bottom at station 16 off Phillipsdale some three-quarters of a mile further down the river. Tidal conditions during both the series were similar and no good reason can be given for the change in the location of the low point. It is interesting to note also the sharp break downward of the bottom curve at station 24, in the last three series, while on August 3 there was a sharp upward break at this point. This station is located at the north of the Seekonk where it receives the full effect on the ebb tide of the sewage from the Town of East Providence. The Tide stages for each of these last three series were quite different from one another. So far as can be determined from the graphs no marked effect on the quality of the water at the bottom in the main body of the Seekonk was caused by the fact that the Blackstone and Ten Mile Rivers were in flood on July 25 and 26.

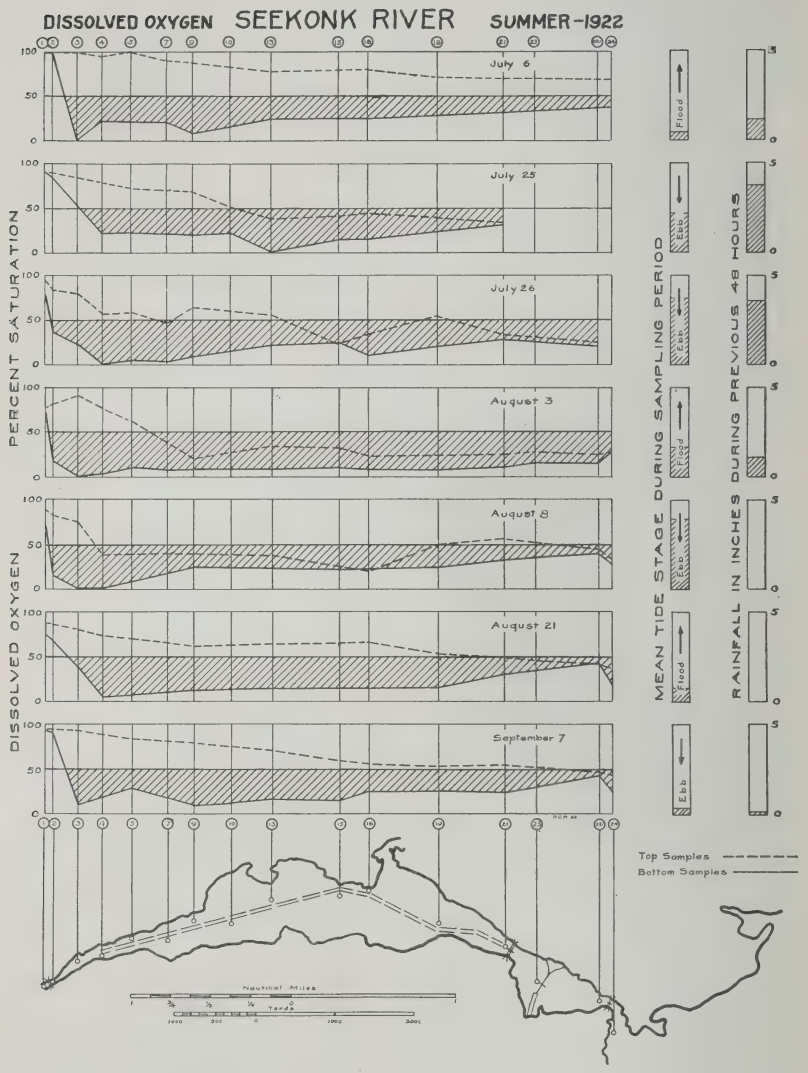


FIG. 5.—Graph showing dissolved oxygen content at different points in the Seekonk River during the summer of 1922. Surface waters indicated by dotted lines, deep waters by solid lines. Shaded areas deficient in oxygen.

The surface samples collected at different parts of the river show a much greater fluctuation in oxygen content than do the bottom samples. On July 6 the oxygen curves for top samples throughout the entire length of the river was above the 50 per cent. line, while on September 7 it did not dip below that line until station 23.1, located just above the Washington Bridge, and on August 21 it first dropped to the safety line at station 21 located just above the Red Bridge. On each of these dates the top oxygen curve shows an almost uniform downward trend as we proceed down the river. The series on July 26 and August 21 were collected on the flood tide while the series on September 7 was collected on the ebb tide. For forty-eight hours previous to the series of August 21 there had been no rain, and during the similar period prior to September 7 there had been only a small amount of rain. On the other hand during the forty-eight hours preceding the series of July 26 there had been over an inch of rainfall, sufficient to cause a material increase in the volume of fresh water entering the Seekonk from its two main tributaries.

On August 3, on the flood tide with about one inch of rain during the preceding 48 hours, and the rivers still in flood from the excessive rainfall of the latter part of July, the top oxygen curve drops below 25 per cent. at station 9, just below Stony Point, then rises about 35 per cent. at stations 13 and 15 located off Bucklins Island and above Phillipsdale, then drops back to about 25 per cent. throughout the lower part of the river. On August 8, with no rainfall during the 48 hours immediately preceding and the tide on the ebb, the top oxygen curve drops below the safety line at station 4 below the Pawtucket sewers, gradually falls to station 16, off Phillipsdale where it coincides with the bottom curve, then rises above the safety line at station 21 above the Red Bridge, then drops back below the 50 per cent. line from the Washington Bridge to the mouth of the river with a sharp downward break at station No. 24, the last sampling point.

The most irregular and perhaps the most interesting curves are those for the top oxygens during the series of July 25 and 26. During the 24 hours previous to July 25 there had been heavy rains, totaling about four and one-half inches, and the Blackstone and Ten Mile were at the highest flood stage ever known in summer, bringing into the Seekonk more than twice the normal volume of water which was practically saturated with oxygen. Samples on both these dates were taken on the ebb tide when the effect of dilution from the tributary streams should be greatest. On July 25 the top oxygen curve is above the 50 per cent. line down to station 10, or for about 1.5 miles below the mouth of the Blackstone. Below station 10 top curve is below the safety line and shows a general downward trend to the Red Bridge which was the last sampling point on that date. On July 26, the curve shows a much greater fluctuation in surface oxygen than on any other date when samples were taken. On this date the curve starts at about 95 per cent. saturation, and shows an irregular downward trend to station 7 where it touches the 50 per cent. line, breaks sharply upward to about 65 per cent. at the next station down the river, then continues with a downward trend crossing the 50 per cent. line below Bucklins Island until it coincides with the bottom oxygen curve at station 15 just above Phillipsdale. Below Phillipsdale the curve again rises until it crosses the safety line at station 19, then shows a marked downward trend to the Red Bridge, the last sampling station on that date. The oxygen curves would indicate an improvement in the quality of the top waters of the

Seekonk on July 26 as a result of flood waters entering from the Ten Mile. No such improvement is indicated, however, in the curves for samples collected the day before when conditions were nearly identical, while on August 8 under practically the same tidal conditions there is a similar upward trend to the top oxygen curve although flow from the Ten Mile was approximately normal.

Conclusions from Seekonk River Studies: From the results of these studies it is evident that the oxygen requirements of the large volumes of sewage and manufacturing wastes now being discharged into the Seekonk are greater than the available oxygen supply. Even with the largely increased dilution due to excessive rainfall and high river flow which prevailed during the past summer the saline waters at the bottom throughout the entire river were far below the safety limit for dissolved oxygen, while the fresher waters at the top in many portions of the river were below that limit more than half of the time.

How much of the responsibility for these conditions is to be attributed to municipal sewage and how much to wastes from the various industrial plants located on the shores of the river cannot be stated at the present stage of our investigations. At the present time the City of Providence has under construction an intercepting sewer to divert to Fields Point the municipal sewage now being discharged from the Butler Avenue and the Pitman Street sewers. This will relieve the burden on the Seekonk, although it will add to the load of sewage now discharged into the Providence River. The City of Pawtucket has plans nearly completed for the construction of intercepting sewers and treatment works to alleviate the nuisance now caused by the sewage discharged at the head of the Seekonk. The Town of East Providence has taken preliminary steps leading toward purification of the sewage discharged in the vicinity of the Washington Bridge. The character and amount of industrial pollution at each source together with its effect on the river must be determined before the share which the various industrial plants must take to relieve existing pollution can be pointed out to them. These are features which could not be covered during the past summer and had to be left for future investigation and study.

The Providence River.

The extreme northerly portion of Narragansett Bay from the junction of the Moshassuck and Woonasquatucket Rivers and extending south for an uncertain distance is known as the Providence River. Authorities differ as to where the Providence River ends and Narragansett Bay begins, some persons claiming that the southerly limit of the river is at Conimicut and Nayatt Points, others that Kettle and Fields Points are the boundary line, while still others claim intermediate points as the junction. From the best available evidence it would appear that below Fields Point should be considered as part of the bay and in the present studies the river will be assumed as ending at Fields Point. On this basis we may describe the Providence River as a tidal estuary forming the upper end of Narragansett Bay from the junction of the Moshassuck and Woonasquatucket River south to a line from Fields Point to Kettle Point. The lower end of the Woonasquatucket River, from its junction with the Moshassuck westerly to Acorn Street in Providence, is subject to tidal influence, and for purposes of investigation and discussion this part of the Woonasquatucket has been

considered as a part of the Providence River pollution zone. The average tidal prism at Fields Point is estimated at about 6,725 million gallons at each tide.

Sources of Pollution: At Fields Point on the west side of the Providence River just above its mouth are located the sewage disposal plant of the City of Providence, the gas plant of the Providence Gas Company, and the oil distributing and distilling plant of the Texas Company, together with a number of smaller industries. At the Gas Company's plant all waste liquors are passed through separators to remove tar and oil, and much of this water is utilized for condenser purposes or for quenching coke thereby materially reducing the volume of wastes discharged into the river. The ammoniacal liquors from this plant are pumped to an ammonia recovery plant operated by the Clapp Ammonia Company, the wastes from which go to the public sewers. At the Texas Company all wastes and oil leakage are conducted to separator tanks where the oil and grease are removed before the waste waters are discharged. While the amount of pollution due to wastes from these sources is now relatively small, the sand and gravel on the shore line at the Gas Company are saturated with gas house waste and tar which work out into the river to a certain extent in hot weather. At this point also considerable gas tar on the bed of the river still remain from the wastes discharged in former years. All the sewage from the City of Providence, averaging some 26 million gallons per day, is collected at the Fields Point Sewage Disposal Plant, where it is treated with lime and settled to remove settleable solids. The treated sewage is discharged only on the ebb tide, but some of the sea water with its load of sewage is brought back with the flood tide into the Providence River and thereby contribute to the pollution. Across the river from Fields Point are the large oil receiving and distributing stations of the Mexican Petroleum Corporation and the Gulf Refining Company. At both of these plants precautions are taken to prevent pollution entering the river, similar to those employed at the Texas Company.

Discharging into the Providence River on the easterly side about 1.5 miles north of Kettle Point is the Seekonk River which contributes a mixture of fresh and salt water of varying degrees of pollution at ebb tide. At the northerly end the Moshassuck and Woonasquatucket contribute an average of about 71.6 million gallons of fresh water per day. As described elsewhere the waters of the Moshassuck are so grossly polluted at the present time that they constitute one of the major sources of pollution of the Providence River. The Woonasquatucket, although it receives considerable pollution, still has a reasonably high oxygen content above the point where it is not affected by the tides.

As far as we have been able to determine, no industrial wastes are being discharged directly into the Providence River as above defined. On the shores of the river are located a number of large power plants from which considerable amounts of condenser waters are discharged. While these condenser waters carry no manufacturing or organic pollution, they have to a very large extent been robbed of their oxygen content by having been heated, and thus tend in a measure to lower the oxygen content of the stream.

Concentrated Studies: Concentrated studies of the oxygen content of the waters in this zone were made on three different dates, two of these being conducted on the ebb tide and one on the flood tide. It was originally planned to

make a number of these studies covering both stages of the tide, but as explained elsewhere owning to weather conditions and heavy rainfall these plans could not be carried out. The results obtained in these three surveys are characteristic and show quite clearly the effect of tidal flow on this pollution zone.

In these surveys as made, the two field parties worked in close co-operation. Party No. 1 with an automobile covered the section from Crawford Street Bridge to Acorn Street, with one station on the lower Moshassuck. Party No. 2 working with the power boat covered the navigable section of the river from Point Street Bridge south to below Fields Point. Starting just before the turn of the tide, each party made consecutive dissolved oxygen determinations at sampling stations in its territory until the next turn of the tide, thus covering the varying conditions during a complete tide stage. The sampling stations covered by these concentrated studies were as follows:

Station No. 5a. Woonasquatucket River at Acorn Street, head of tidal influence.

Station No. 4a. Woonasquatucket River at Gaspee Street.

Station No. 3a. Moshassuck River at Promenade Street just above junction with Woonasquatucket River.

Station No. 2a. Providence River at north side of Market Square just below junction of Moshassuck River.

Station No. 1a. Providence River at Crawford Street.

Station No. 25. Providence River at Point Street.

Station No. 26. Providence River just north of Wilkesbarre Pier at entrance of Seekonk River.

Station No. 31. Providence River opposite Gulf Refining Company.

Station No. 35. Providence River just south of Fields Point sewer outfall.

Station No. 38. Upper bay near Spar Buoy No. 19, about one-half mile south of Fields Point Sewer out fall.

The location of these various sample stations are shown on the map, Fig. 6.

On July 19, sampling was started at 10:30, or just before low tide. It was intended to carry this series through until after high tide but owing to an unavoidable accident sampling had to be discontinued about one hour before high tide stage was reached. The results obtained in this series are shown graphically in Fig. No. 7.

At Acorn Street, the head waters of tidal influence in the Woonasquatucket River, and about one mile above the mouth of the Moshassuck River, the dissolved oxygen values during the day ranged between 79 and 86 per cent., all samples being above the danger line so far as oxygen content was concerned. As was learned from other studies, however, had it been possible to continue sampling for another hour there is little question that the effect of backing up of the polluted waters of the Moshassuck and Providence Rivers by the incoming tide would have been reflected by a drop in dissolved oxygen just before the end of the flood tide stage.

At Gaspee Street, about one-fourth mile above the junction with the Moshassuck, the oxygen values ranged between 54 and 88 per cent. While all samples

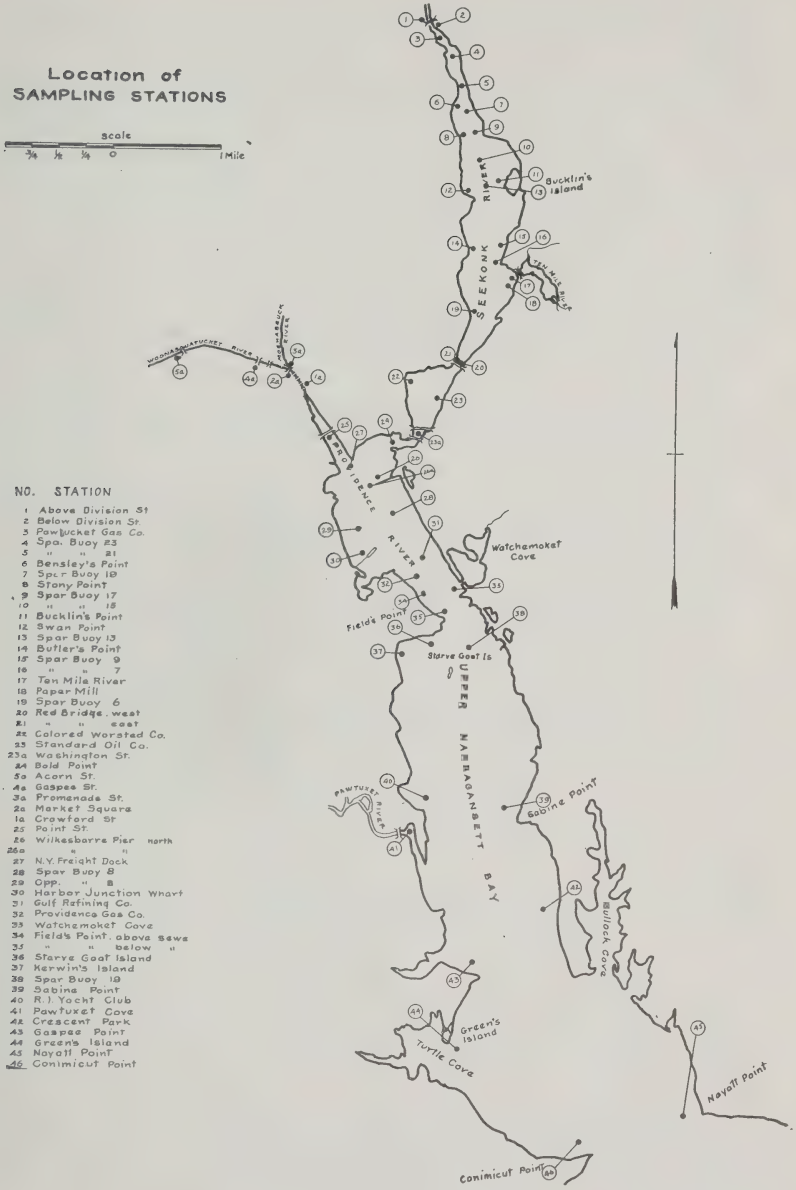


FIG. 6.—Map of Upper Narragansett Bay, Providence, and Seekonk Rivers, showing location of Sampling Stations.

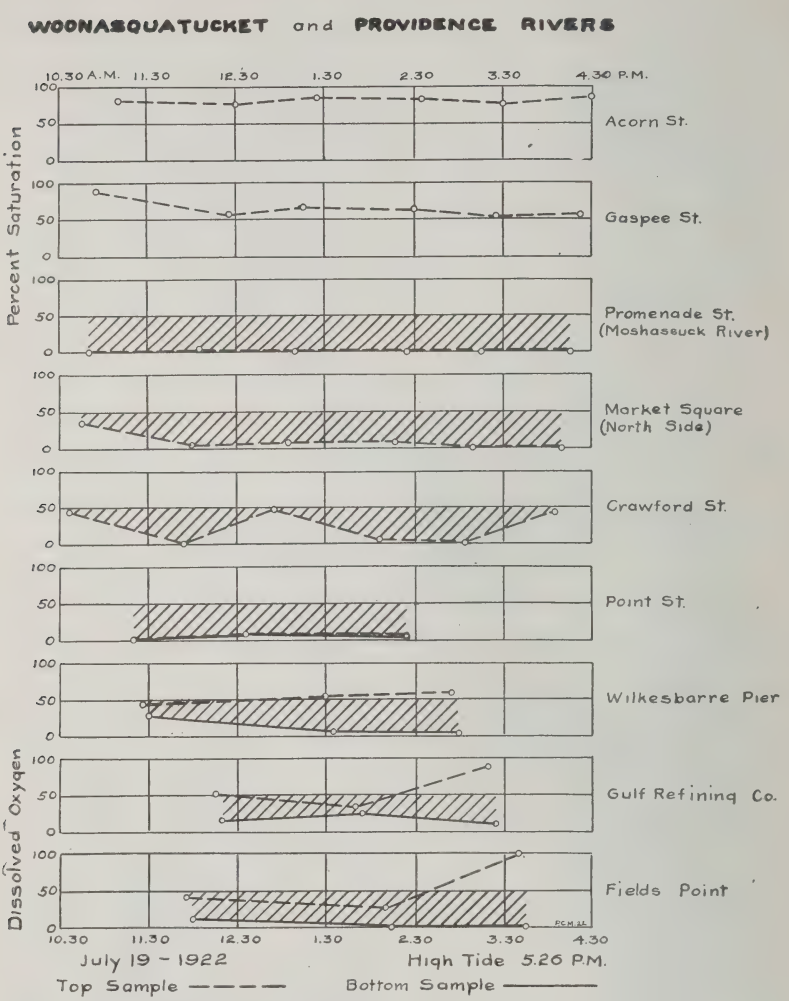


FIG. 7. Graph showing variation in dissolved oxygen in Providence River at different points during flood tide on July 19, 1922.

at this station contained over 50 per cent. oxygen saturation, the influence of the backing up of the polluted waters from the lower portions of the river can be observed as soon as the tide began to turn, and continue throughout the flood stage.

Samples taken in the Moshassuck River, just above its junction with the Woonasquatucket, did not show dissolved oxygen at any time during the series.

At Market Square, just below the confluence of the Moshassuck and Woonasquatucket Rivers, a sample taken before the tide turned showed an oxygen content of about 35 per cent. saturation. With the turn of the tide and the holding back of the oxygen bearing waters of the Woonasquatucket by tidal influence a decided drop in oxygen content occurred at this point, and when the last sample was taken all oxygen had disappeared from the water.

At Crawford Street Bridge, the head waters of navigation a wide fluctuation in the oxygen content of the water is to be noted, the oxygen values ranging from nearly 50 per cent. saturation to zero at various times. At the present time no reasonable explanation can be given for this wide fluctuation, although possibly it might have been caused by stirring up of decomposing matters on the bottom by backwash from vessels in the navigable waters below. A similar fluctuation in oxygen values will be noted at this station in later studies made on the ebb tide.

At Point Street Bridge samples collected from both top and bottom were practically devoid of oxygen throughout the series.

At the sampling station at the mouth of the Seekonk River of the Wilkesbarre Pier, the top samples showed a slight increase in oxygen content as the tide rises. On the other hand there is a decided drop in the oxygen content of the bottom samples, and during the latter part of the flood stage these samples were practically devoid of oxygen.

At the station off the Gulf Refining Company's pier a distinct drop is to be observed in the oxygen content of the top sample and a slight increase in the oxygen of the bottom samples during the first portion of the flood tide followed by a sharp rise in oxygen at the top and a reduction to nearly zero at the bottom as the height of the tide increases.

At the sampling station just below the Fields Point sewer outfall a decline in oxygen content is observed in the top sample during the first half of the flood tide stage followed by an increase to the saturation point later in the day. Bottom samples collected at this station showed a small amount of oxygen in the forenoon, but were entirely devoid of oxygen during the middle and end of the flood tide stage.

Concentrated studies of the Woonasquatucket-Providence River section were made under ebb tide conditions on August 9 and on August 24. In general the results obtained in both series were similar and confirm one another, although pollution was somewhat more marked at most of the sampling points on the earlier date. The results of dissolved oxygen determinations at the various stations on these two dates are shown graphically in Figures 8 and 9.

At Acorn Street, the head of tidal influence in the Woonasquatucket, relatively low oxygen values were obtained at high tide, owing to backing up of the more seriously polluted waters from the Moshassuck and Providence Rivers. As the tide falls an increase in dissolved oxygen is to be noted which reached maximum at low tide when the stream flow at this station was entirely from the river above.

At Gaspee Street Bridge the same general changes in the character of the waters are to be observed as at the Acorn Street station. At this point, however, oxygen values were considerably lower at all stages of the tide in both series then at the station further up the river, and at high tide these oxygen values were well below the 50 per cent. mark.

At the station on the lower end of the Moshassuck a small amount of oxygen was found in the top samples collected during the early ebb tide on August 9, although bottom samples contained no oxygen. Later top samples on this date and all samples at this station on August 24 were devoid of oxygen.

At the Market Square sampling station, below the confluence of the Moshassuck and Woonasquatucket, oxygen values of about 75 per cent. saturation were obtained on top samples during the first hour of ebb tide these being followed by drop in oxygen to about 40 per cent. by the end of the second hour and by zero oxygens at later tide stages. A few bottom samples collected on the early stages of the ebb tide on this date were without dissolved oxygen. The series on August 24 shows a marked fluctuation in oxygen of top samples. From 10:40 to 11:30 there was an increase from 25 per cent. to about 50 per cent. saturation; the 12:45

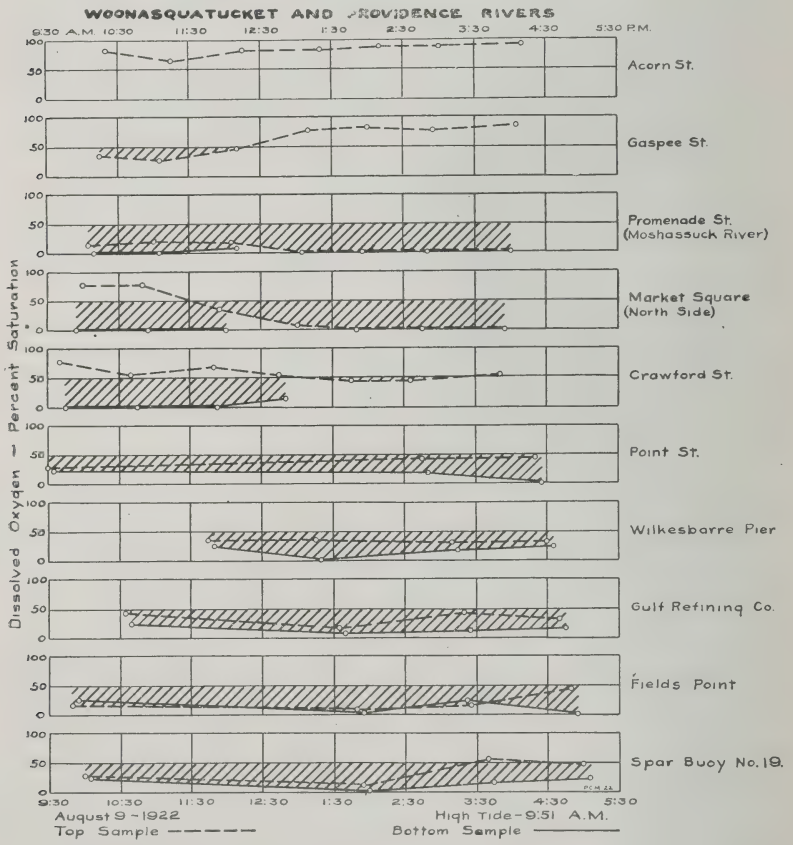


FIG. 8.—Graph showing variation in dissolved oxygen in Providence River at different points during ebb tide on August 9, 1922.

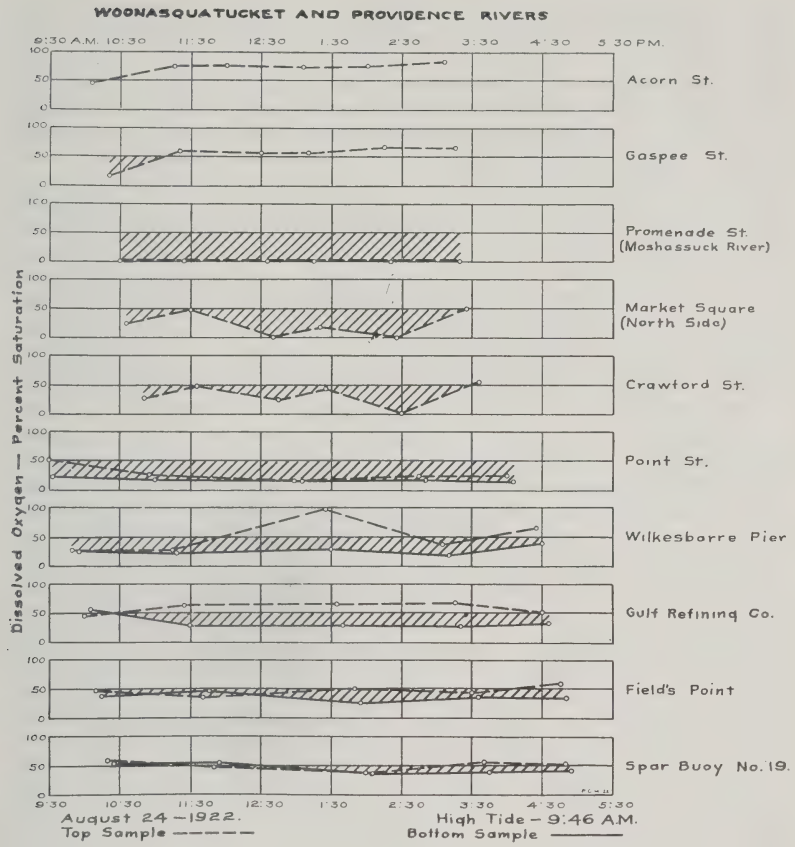


FIG. 9.—Graph showing variation in dissolved oxygen in Providence River at different points during ebb tide on August 24, 1922.

sample contained no oxygen; the 1:20 sample again showed a small increase; the 2:40 sample was again devoid of oxygen, while at 3:25 just before low tide the sample was about 50 per cent. saturated with oxygen.

At Crawford Street Bridge also there was considerable fluctuation in the condition of the water near the surface throughout the ebb tide stage in both series. On August 9 top samples at this station contained 50 per cent. or more dissolved oxygen during the first three hours of the ebb tide. During the latter part of the tide stage the oxygen values dropped slightly below the 50 per cent. mark, but a slight increase is to be observed in the sample collected at about the time the tide turned. Bottom samples on this date were without oxygen during the first two hours of the tide stage, although some oxygen was found in a sample collected

about three hours after high tide. On August 24 the same fluctuation was noted in oxygen values at this station as was observed at the Market Square station. On both of these dates, the top samples at this station were of considerably higher oxygen content than were similar samples at the sample stations above and below. A similar, but less marked, peculiarity was noted at this point during the flood tide study previously discussed. At the present time no data are available to explain these apparent discrepancies.

At Point Street all samples from both top and bottom contained less than 50 per cent. oxygen on both August 9 and August 24. There was a small but gradual increase in the oxygen content of top samples collected throughout the series of August 9, while on August 24 there was a gradual decrease during the first three hours and a slight increase during the last three hours of the ebb tide. Bottom samples at this station show a marked similarity on both dates during the entire ebb tide. Samples collected shortly after the tide had begun to come in on August 9 show a decrease in oxygen to the zero point, although no such decrease is recorded on August 24.

At the station at the mouth of the Seekonk off the Wilkesbarre Pier, no samples were collected on August 9 until the tide had been on the ebb for about two hours. After this time there was a small but gradual reduction in the oxygen of the top samples and a drop to zero followed by a gradual increase in oxygen in the bottom samples. All samples on this date contained less than 40 per cent. oxygen. On August 24, the bottom samples fluctuate between 21 and 27 per cent. oxygen during the first four hours of the ebb, dropping to 19 per cent. just before low tide and then increasing to approximately 40 per cent. in about an hour after the tide had begun to come in. The top samples on this date show oxygen practically constant at about 25 per cent. saturation during the first hour of the ebb, an increase practically to saturation at the middle of the tide stage, a drop to about 40 per cent. just before low tide, and then an increase to about 60 per cent. during the first hour of the incoming tide.

At the station off the Gulf Refining Company, on August 9 the first samples collected about one hour after high tide showed about 25 per cent. oxygen at the bottom and about 45 per cent. at the top. During the following three hours the oxygen in the top decreased to about 15 per cent. then rose to nearly 50 per cent. just before low tide, and then began to diminish as the tide began to come in. At the bottom there was a slight reduction during the first three hours and then a very slight increase in oxygen during the latter part of the tide stage continuing after the tide turned. All samples both top and bottom were below the 50 per cent. mark. On August 24, the oxygen values on both top and bottom samples were somewhat higher than in the previous series. At the time the first samples were collected, about one-half hour after high tide, both samples showed about 50 per cent. oxygen saturation, the bottom sample being slightly higher in oxygen than the top sample, a rather unusual condition. On this date the oxygen at the top increased to about 60 per cent. during the first hour and remained practically constant until after the tide began to come in, when a drop in oxygen is to be observed. On the other hand the oxygen at the bottom dropped from 55 to 25 per cent. during the first hour of the ebb tide, remained practically constant at this value until after the turn of the tide.

At the station below the Fields Point sewer outfall very low oxygen values were obtained on both top and bottom samples during the first four hours of ebb tide on August 9. Just before low tide there was an increase in oxygen in both samples, followed by a decided drop in oxygen at the bottom and a still further increase in oxygen at the top after the tide began to come in. On August 24, oxygen values at this point were somewhat higher than on the preceding date. At the top the oxygen fluctuated somewhat but remained very close to the 50 per cent. line throughout the day while at the bottom there was a similar fluctuation between 45 per cent. and 25 per cent. It must be borne in mind that the sewage is discharged at Fields Point on the ebb tide, *i. e.*, during the sampling period on these dates.

At Spar Buoy 19, below the mouth of the Providence River, on August 9, the oxygen content of the top and bottom samples dropped from about 25 per cent. to 10 per cent. and zero respectively during the first four hours of ebb tide. During the last two hours of ebb, however, the top oxygen rose to slightly over 50 per cent. and the bottom oxygen increased to about 15 per cent. On August 24, at this station the top and bottom oxygen values were in close proximity for the entire tide stage. The top oxygen decreased from about 55 per cent. to about 40 per cent. during the first four hours and then increased to just over 50 per cent. at about the time the tide turned. At the bottom the oxygen dropped from just over 50 per cent. to about 40 per cent. during the first four hours of ebb tide and remained practically constant at this value until about one hour after low tide.

Oxygen demand determinations were made in these two latter series on all samples which contained no dissolved oxygen. At Crawford Street Bridge an oxygen demand of 213 p.p.m. was found on one sample collected on August 9, while at Market Square on the same date an oxygen demand as high as 104 p.p.m. was obtained. On August 24, the oxygen demand at most of the stations where zero oxygen values were found averaged between 25 and 50 parts per million. At the stations at Market Square, at Spar Buoy 19 and off the Gulf Refining Company, however, oxygen demand values ranging between 80 and 100 parts per million were obtained on certain samples.

Miscellaneous Studies: As has been previously noted the Providence River is the connecting link between the Moshassuck and Woonasquatucket Rivers on the north, the Seekonk River on the east and the upper bay at the south. For this reason our studies of these other sections have overlapped into the Providence River in order that the influence of one section upon another might be observed. The results of tests for dissolved oxygen at various points in the Providence River as obtained in studies of these other sections on nineteen different dates between June 28 and September 12, together with the stage of the tide when the samples were taken, have been collected in Table No. 5. These results furnish additional data which serve to confirm the findings of the concentrated studies and to prove that the conditions similar to those observed in the concentrated studies might have been obtained at almost any other time during the summer of 1922.

In the tidal section of the Woonasquatucket River oxygen values well above the safety limit were obtained at Acorn Street on all five dates when samples

TABLE NO 5.—DISSOLVED OXYGEN IN VARIOUS PARTS OF THE PROVIDENCE RIVER UNDER DIFFERENT TIDAL CONDITIONS.

1922.	Acorn Street.		Gaspee Street.		Market Square.		Promenade Street.		Crawford Street.		Point Street.		Bold Point.		Wilkes-barre Pier.		Fields Point above sewer.		Fields Point below sewer.	
	Tide-Stage.	Oxygen.**	Tide Stage.	Oxygen.	Tide Stage.	Oxygen.	Tide Stage.	Oxygen.	Tide Stage.	Oxygen.	Tide Stage.	Oxygen.	Tide Stage.	Oxygen.	Tide Stage.	Oxygen.	Tide Stage.	Oxygen.	Tide Stage.	Oxygen.
June 28											11 F	26–89	9 E	91–63			4 E	65–39	4 E	59–15
" 29																	4 E	43–11	4 E	37–25
" 30											5 F	25–0					9 F	49–11	9 F	41–30
July 6	9 E	96	9 E	58	8 E	85					10 E	28–55	11 E	68–37						
" 7							9 E	65	8 E	73	9 E	87–32	11 E	100–96	9 E	66–37			10 E	47–0
" 12							11 F	47	11 F	65										
" 13											7 F	12–15	8 F	45–22						
" 17											4 F	62–27			5 F	84–25	6 F	87–22	7 F	99–26
" 19	F	83	F	62	F	5			F	20	F	9–7	F	64–19	F	56–3				
" 24							4 E	83	8 F	88	1 F	31–26	1 F	28–12	L	32–0	1 E	41–0	1 E	35–0
" 31							3 F	59	2 F	35					2 E	34–38	H	64–38	11 F	52–52
Aug. 3											9 F	39–24	8 F	30–32						
" 3											11 E	37–21	L	20–26						
" 7	5 E	74	5 E	72	4 E	45														
" 9	E	81	E	58			E	0	E	28	F	37–11	E	23–23	F	30–23				
" 9											E	41–18			E	33–14				
" 21	7 E	73	7 E	45	7 E	51					5 F	29–13	5 F	31–18	L	39–24			11 E	42–0
" 24	E	71	E	53	F	23			E	12	F	22–14	F	34–24	F	55–39				
" 24											E	21–17	E	31–30	E	55–22				
" 27							9 F	72	9 F	72										
Sept. 5	8 E	82	7 E	85	7 E	62														
" 7							4 E	59	3 E	71			10 E	44–25	9 E	40–20	9 E	52–23		
" 10							11 F	65	11 F	45										
" 11							8 F	65	8 F	63										
" 12	7 F	84	8 F	84	7 F	53														

Tide Stage Figures—tide stage to nearest half hour.
F = tide on flood. E = tide on ebb.
H = high tide. L = low tide.

Examples 9 E, 4.5 hours after tide began to ebb.
4 F, two hours after tide began to come in.

**Dissolved Oxygen* First figure, one foot below surface.
Second figure, one foot above bottom.
Where only one figure given, water insufficient depth for top and bottom samples.

were collected. At Gaspee Street the oxygen was just under the safe limit on one of these dates and just above the limit on another. At the head of the Providence River at Market Square the oxygen was below 50 per cent. on one date and just above on two others. At Promenade Street on the tidal section of the Moshassuck much better results were obtained then were indicated by the concentrated studies, oxygen values above 50 per cent. saturation being obtained on seven of the eight dates when examinations were made. At Crawford Street on the Providence River low values were found on two out of eight dates, both of these being obtained when the tide was coming in.

At Point Street samples were collected on nine different dates. On five of these dates the oxygen at both top and bottom was below the safe limit and on the other four dates low values were obtained on either the top or bottom sample. As a rule the lowest results were obtained at this station when the tide was on the flood. Samples collected at this station one-half hour before and 4.5 hours after low tide on August 3 were all below 40 per cent. oxygen content.

At the Bold Point station in the mouth of the Seekonk, examinations were made on eight dates, low oxygen values being obtained at both top and bottom on five dates. On the other hand on July 7 just before low tide the water at both top and bottom was practically saturated with oxygen and on June 28 about 1.5 hours before low tide the top sample contained 91 per cent. and the bottom sample contained 63 per cent. oxygen. On August 3 samples collected at this station at low tide showed 20 per cent. oxygen at the top and 26 per cent. at the bottom, while four hours later there was an increase in oxygen to 30 per cent. at the top and to 32 per cent. at the bottom. On August 21 samples collected one-half hour and 2.5 hours after low tide showed practically the same results, the top samples containing 36 and 37 per cent. and the bottom samples 16 and 18 per cent. of oxygen respectively.

At the station off the Wilkesbarre Pier, on four different dates low oxygen values were found at both top and bottom and on two other dates the bottom samples were below the safety line.

At the station above the Providence sewer outfall low oxygen values were obtained at the bottom on each of the seven dates tests were made, although the oxygen at the surface on four of these dates ranged from 52 to 87 per cent. On July 24 no oxygen was present in the water at the bottom one-half hour after high tide. At the station below the sewer outfall oxygen determinations on eight dates show the water at both top and bottom below the safe limit on five dates and below the limit at the bottom on two other dates. On July 7 and August 21, with the tide on the ebb for about five to five and one-half hours, and on July 24 about one-half hour after high tide, the samples collected at the bottom at this station were entirely devoid of oxygen.

Sources of Pollution and Remedies: The present condition of the Providence River can be attributed to the pollution coming into it from three major sources. The Moshassuck River on the north, and the Seekonk on the east with their load of pollution must both discharge through the Providence River. At the mouth on the west side is the outlet for all the sewage of the City of Providence. Without question the pollution of the tidal section of the Woonasquatucket is largely if not entirely due to organic matters brought down by the Moshassuck

and thrown back by the flood tide. Much of the trouble in the upper section of the Providence River through Market Square is also due to the filth brought down by the Moshassuck and either held there by the ebb and flow of the tides or precipitated on the bottom as the result of admixture with salt water. It is also evident that more or less of the pollution discharged through the Seekonk comes back up the Providence River above the confluence of these two rivers and that some of the sewage discharged on the ebb tide at Fields Point is again brought back into the lower Providence River with the flood tide.

It is impossible from the evidence available at the present time, however, to determine just how far up the river pollution from either of these latter sources is carried or in what degree either source is responsible for the present unsavory conditions. We cannot differentiate by chemical means between the pollution from these two sources after it has become mixed in the river, and reliance will have to be placed on float studies to determine these factors.

It is evident then that in order to clean up the Providence River we must materially reduce the pollution of the Moshassuck and Seekonk Rivers and of upper Narragansett Bay. Improvement in the conditions of any one of these sources of pollution might result in some improvement also in the Providence River, but this improvement would be local in character and would not materially affect other sections of the river. Even should all sewage and manufactural wastes be completely removed from the Moshassuck and Woonasquatucket, it is doubtful if the Providence River through Market Square, and the tidal section of the Woonasquatucket would cease to be a nuisance in the summer. Located in the heart of the city any shallow tidal estuary in which considerable areas of mud flats are exposed at low tide is sure to be offensive both to sight and smell.

Some years ago Samuel M. Gray, then city engineer of Providence, suggested the construction of a dam and tide gates at Crawford Street as a means for improving these tidal sections. If this suggestion was carried out the mud flats now exposed at low tide would be covered with water all the time and any odors arising from them would be largely absorbed instead of being dissipated into the air. The basin so formed would be filled with fresh water and as already explained, fresh water even under putrefactive conditions is less likely to be offensive than salt water. Furthermore the deposition of suspended matters through the precipitating effect of admixture of fresh and salt water would cease and most of the pollution brought down by the rivers would be carried through the tide gates at ebb tide to a point where a much larger volume of sea water would be available for purposes of dilution. The Woonasquatucket section would then become a basin which would lend itself to further development as a part of the water park under the plans already laid out by the City Planning Commission.

Another plan which has been suggested would be to cover the river through Market Square. This method of covering up offensive waters has proved reasonably successful in other places and might be expected to work equally well here. With the growing traffic problem in Providence there is little question that eventually this section will have to be covered even if this is not done for sanitary reasons. However, this would not relieve the nuisance existing in the lower part of the Woonasquatucket unless that section were also covered. Perhaps

a combination of these two plans might prove to be the best and most economical solution for both the nuisance and the traffic problems. At any rate the permanent improvement of these sections of the Providence and Woonasquatucket Rivers needs immediate and serious consideration and action, and is independent of such improvements as can be reasonably expected in the condition of the Moshassuck.

Upper Narragansett Bay.

For purposes of discussion that portion of Narragansett Bay north of Conimicut and Nayatt Points and extending up to the mouth of the Providence River at Fields Point has been termed upper Narragansett Bay. This body of water is about 5.5 miles long and has a maximum width of about 2.06 miles, with a total water surface of about 4.05 square miles.

On the west side, about 2.5 miles south of Fields Point, the Pawtuxet River empties into the bay some 250 million gallons each day of fresh water which has already received a considerable amount of industrial pollution. At Vanity Fair, nearly opposite the mouth of the Pawtuxet River, is the large oil refinery and distributing station of the Standard Oil Company. At this plant all surface waters together with condenser waters and other wastes from the refinery are passed through separator tanks to remove oil before being discharged into the bay. The refinery wastes carry considerable dirt and soluble matter and as discharged usually have a strong odor not unlike that of poor grade kerosene. The volume of waste waters fluctuates considerably from time to time depending upon the necessity for conserving water for condensing purposes during dry weather. At Fields Point, just north of the junction of the Providence River with the upper bay, the sewage from various parts of the City of Providence is brought together and after clarification discharged upon the ebb tide.

The shape or topography of this part of the bay has considerable influence upon the extent of pollution. On the ebb tide the Providence sewage together with the badly polluted waters from the Providence and Seekonk Rivers, and the cleaner waters from the Pawtuxet must pass through this section on their way to the lower bay. On the flood tide, considerable amounts of saline water relatively free from pollution are forced back into this section, some of this going through into the Providence and Seekonk Rivers. The ebb and flow of the tides tend to produce a shuttle effect, however, with the result that a certain part of the pollution coming down from above Fields Point on the ebb tide does not pass out into the lower bay, but is driven back again by the incoming tide.

Results of Dissolved Oxygen Studies: In our studies of conditions in the upper bay eleven sampling stations were established for the purpose of comparison, these being generally at points close to the stations used by the Commissioners of Shell Fisheries in their study of this area in 1918. These sampling stations were as follows:

	Station No.	Shellfish Com. Station No.
N. E. of Starvegoat Island	36	2
Off Edgewood Beach	37	1
Spar Buoy No. 19	38	..
N. W. of Sabin Point	39	4
N. E. of R. I. Yacht Club	40	3
In Pawtuxet Cove	41	..
N. E. of Gaspee Point	42	6
Off Crescent Park	43	5
S. E. of Greene's Island	44	7
N. W. of Nayatt Point	45	9
N. E. of Conimicut Point	46	10

The studies of this area, for reasons which have been discussed elsewhere, were not as systematic or as full as was planned, or as was the case with the other studies reported above. Nevertheless dissolved oxygen determinations were made at practically all of these stations on six to eight different dates at more or less regular intervals between June 28 and September 7.

On June 30, the first samples in the upper end of the bay were collected just before high tide, while those further down were collected on the ebb stage. On this date the oxygen content of both top and bottom samples was in nearly all cases below the 50 per cent. mark as far down as the Rhode Island Yacht Club. The lowest point as might be expected was opposite Fields Point and a gradual rise can be noticed until a point opposite Crescent Park is reached. From here on there is a decided rise and both top and bottom samples are practically saturated over the rest of the course.

On July 17, with high tide at 3:16 P. M., sampling was started at the upper end of the bay at 12:10 and completed at 4:25 at Conimicut Point. This schedule gave a high stage of tide on all samples, and at the time the sewage was being discharged at Fields Point the samples were being collected at the lower end of the bay. This series was therefore probably taken under about as favorable conditions as could ordinarily be obtained. This is reflected in the dissolved oxygen results, high values being obtained on both top and bottom samples at all stations except that in Pawtuxet Cove where a low value was obtained at the bottom.

On July 24, sampling was started about two hours after high tide at Nayatt Point and completed at the Providence River just before low tide. Samples at the southerly points were taken before the sewage discharged on that date had had time to reach them, but this sewage was met as the sampling continued north. At the four southerly stations oxygen values even at the surface were considerably below the saturation point, although results below 50 per cent. were not obtained at either top or bottom south of Pawtuxet Cove.

On July 31, another series of samples was taken under nearly the same conditions as on July 17. On this date, however, the dissolved oxygen figures were considerably lower at all stations, and the zone showing oxygen near or below the safe limit at the bottom extended as far south as Gaspee Point.

The series of August 8, August 21, and September 7, were repetitions of series above discussed so far as tidal conditions were concerned and the drift of pollu-

tion down the bay as represented by oxygen studies is similar. One important fact should be emphasized, however, and that is that as the summer advanced oxygen values at practically all stations became lower and lower and the zone in which the bottom oxygens were below the safe limit moved further down the bay. The results of these various studies are shown in Table No. 6.

Conclusions on the Upper Bay: The oxygen values obtained throughout the past summer on this section of the bay were similar in most particulars to those found in 1918 by the Commissioners of Shell Fisheries, in the same general locations. There is one marked difference, however, less available oxygen was found near the bottom at the northerly stations in 1918 than was found at the same points in 1922. In other words conditions were slightly better in 1922. In 1918, chemcial precipitation of Providence sewage was suspended, but was in full operation during 1922. It must be borne in mind also that owing to high rainfall the sewage discharged was more dilute, and also the amount of oxygen brought in by the flooded rivers was far in excess of the amount available during a summer of low rainfall such as 1918. However, with oxygen values below the safety line as far south as Gaspee Point at times, conditions in the upper bay are certainly sufficiently bad to warrant attention.

In attempting to establish the limits of pollution which may properly be permitted in our different public waters we must take into due consideration the use of those waters and of their shores. In the case of the pollution zones discussed in previous chapters the use of the waters and shores at the present time is almost entirely commercial and industrial. So far as those waters themselves are concerned, if the pollution is reduced and controlled to such an extent that they do not at any time become offensive to sight and smell, we may consider that a reasonably satisfactory condition had been obtained.

In the case of the upper bay other factors must be taken into consideration. The shores of the upper bay on the west side for practically the entire distance from Fields Point to Conimicut, and on the east side from Riverside to Nayatt Point are closely built up with permanent homes or summer cottages. Just south of Fields Point is the reservation of the Metropolitan Park system known as Edgewood Beach. On the east shore below Riverside is the large amusement resort known as Crescent Park. Both Edgewood Beach and Crescent Park are equipped with bath houses. Bathing in the waters of the bay is a popular summer pastime both of summer residents and of visitors to these resorts. Boating is also popular and the upper bay in summer is the anchorage of a large fleet of pleasure boats. Clams and quahaugs are abundant and are largely gathered for food by both summer residents and by commercial fishermen. In earlier days many hundred acres of ground in this section of the bay was also used for oyster culture.

These are some of the factors which must be taken into consideration in any decision as to what use may justly and fairly be made of these same waters as means for the disposal of city sewage and manufacturing wastes. If these uses of these waters by the public are to be retained, and if the large investment in permanent and summer homes on the shores is to be protected it is evident that much higher standards of water quality must be established than would be the case for waters whose use is largely or entirely industrial and commercial.

THE LIBRARY OF THE
OCT 16 1940
UNIVERSITY OF ILLINOIS

TABLE NO. 6.—DISSOLVED OXYGEN IN VARIOUS PARTS OF UPPER NARRAGANSETT BAY UNDER DIFFERENT TIDAL CONDITIONS.

	June 28.		June 29.		June 30.		July 24.		July 31.		August 8.		August 21.		September 7.	
	Tide* Stage.	Oxy-gen.**	Tide Stage.	Oxy-gen.	Tide Stage.	Oxy-gen.	Tide Stage.	Oxy-gen.	Tide Stage.	Oxy-gen.	Tide Stage.	Oxy-gen.	Tide Stage.	Oxy-gen.	Tide Stage.	Oxy-gen.
Watchemoket Cove	5 E	50–53	5 E	65–45	9 F	23–18	.....	.....	1 E	29	.....	.....	.....	.....	.....	.....
Fields Point, above sewer	4 E	65–39	4 E	43–11	9 F	49–11	L	41–0	1 E	64–38	.....	.....	.....	.....	8 E	52–23
Fields Point, below sewer	4 E	59–15	4 E	37–25	9 F	41–30	11 E	35–0	H	52–52	.....	.....	11 E	42–0	.....	.....
Starvegoat Island	.....	.....	7 E	53–60	2 E	46–25	10 E	28–28	11 F	82–71	.....	.....	.....	.....	.....	.....
Kerwins Beach	.....	.....	.....	.....	2 E	45–23	.....	.....	11 F	29	.....	.....	10 E	18	6 E	37–25
Spar Buoy No. 19	.....	.....	6 E	54–33	10 F	46–50	11 E	78–13	H	85–47	.....	.....	.....	.....	8 E	38–38
Sabine Point	.....	.....	7 E	59–100	3 E	58–52	9 E	31–29	10 F	69–35	8 E	52–53	9 E	63–65	5 E	32–41
R. I. Yacht Club	.....	.....	8 E	54–38	2 E	56–76	9 E	41–23	11 F	73–41	8 E	64–41	9 E	52–52	6 E	39–25
Pawtuxet Cove	.....	.....	.....	.....	.....	.....	8 E	66–23	10 F	78–61	9 E	75–44	8 E	83–25	5 E	45–81
Crescent Park	.....	.....	.....	.....	4 E	58–62	6 E	54–54	7 F	77–50	.....	.....	.....	.....	4 E	50–46
Gaspee Point	.....	.....	.....	.....	4 E	76–74	7 E	65–57	7 F	78–50	9 E	80–67	8 E	67	4 E	41–42
Green's Island	.....	.....	.....	.....	5 E	100–90	5 E	82–56	6 F	80–62	.....	.....	.....	.....	3 E	68–38
Nayatt Point	.....	.....	.....	.....	6 E	100–100	4 E	73–59	5 F	100–100	11 E	75–77	7 E	71–66	2 E	88–49
Conimicut Point	.....	.....	.....	.....	6 E	100–100	5 E	74–72	6 F	96–82	10 E	82–88	7 E	77–77	3 E	66–48

**Tide Stage* Figures—tide stage to nearest half hour.
F = tide on flood. E = tide on ebb.
H = high tide. L = low tide.

Examples 9 E, 4.5 hours after tide began to ebb.
4 F, two hours after tide began to come in.

***Dissolved Oxygen* First figure, one foot below surface.
Second figure, one foot above bottom.
Where only one figure given, water insufficient depth for top and bottom samples.